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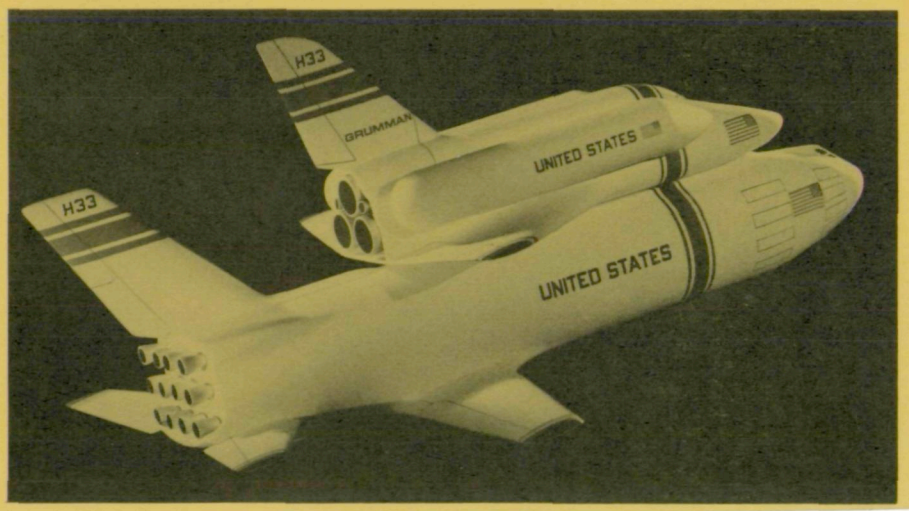
alternate
space shuttle
concepts
study

MSC – 03811
FINAL REPORT
(E-2)

# Part III
# Engineering and Development Plan

# Volume II
# ORBITER VEHICLE

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6 JULY 1971

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NORTHROP

# alternate space shuttle concepts study

MSC – 03811

**FINAL REPORT**

**(E-2)**

# Part III Engineering and Development Plan

# Volume II ORBITER VEHICLE

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## FOREWORD

This document is one of a series prepared in accordance with Contract NAS 9-11160, Study of Alternate Space Shuttle Concepts. Listed below are the final documents required by Data Line Items Nos. 11 through 15 of the contract. Those listed under B & P Documents were developed under the Grumman/Boeing Bid and Proposal effort in anticipation of proposals for a Space Shuttle System industry competition. The letter to the right of each document title is a unique volume identifier which appears in the upper right hand corner of the corresponding document cover.

### CONTRACT DOCUMENTS

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| Executive Summary | |
| Technical Summary | |
| Volume I Shuttle Definition | A |
| Volume II Orbiter Definition | B-1 |
| Volume II Orbiter Definition | B-2 |
| Volume II Orbiter Definition | B-3 |
| Volume II Orbiter Definition | B-4 |
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### B & P DOCUMENTS

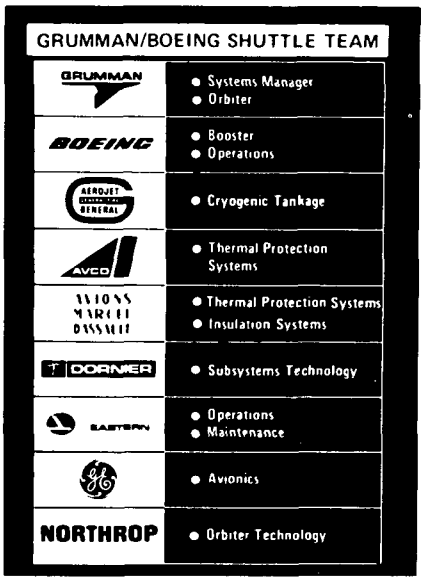
| | | | |
|---|---|---|---|
| Program Management Plan | J | Logistics and Maintenance Plan | N |
| Manufacturing Plan | K | Quality Assurance Plan | P |
| Integrated Test Plan | L | Reliability and Maintainability Plan | Q |
| Facilities Plan | M | Safety Plan | R |

# INTRODUCTION

## ALTERNATE SPACE SHUTTLE CONCEPT STUDY

The study of Alternate Space Shuttle Concepts (ASSC) was initiated on July 6, 1970, in parallel with studies of the fully reusable two-stage-to-orbit earth orbital shuttle.

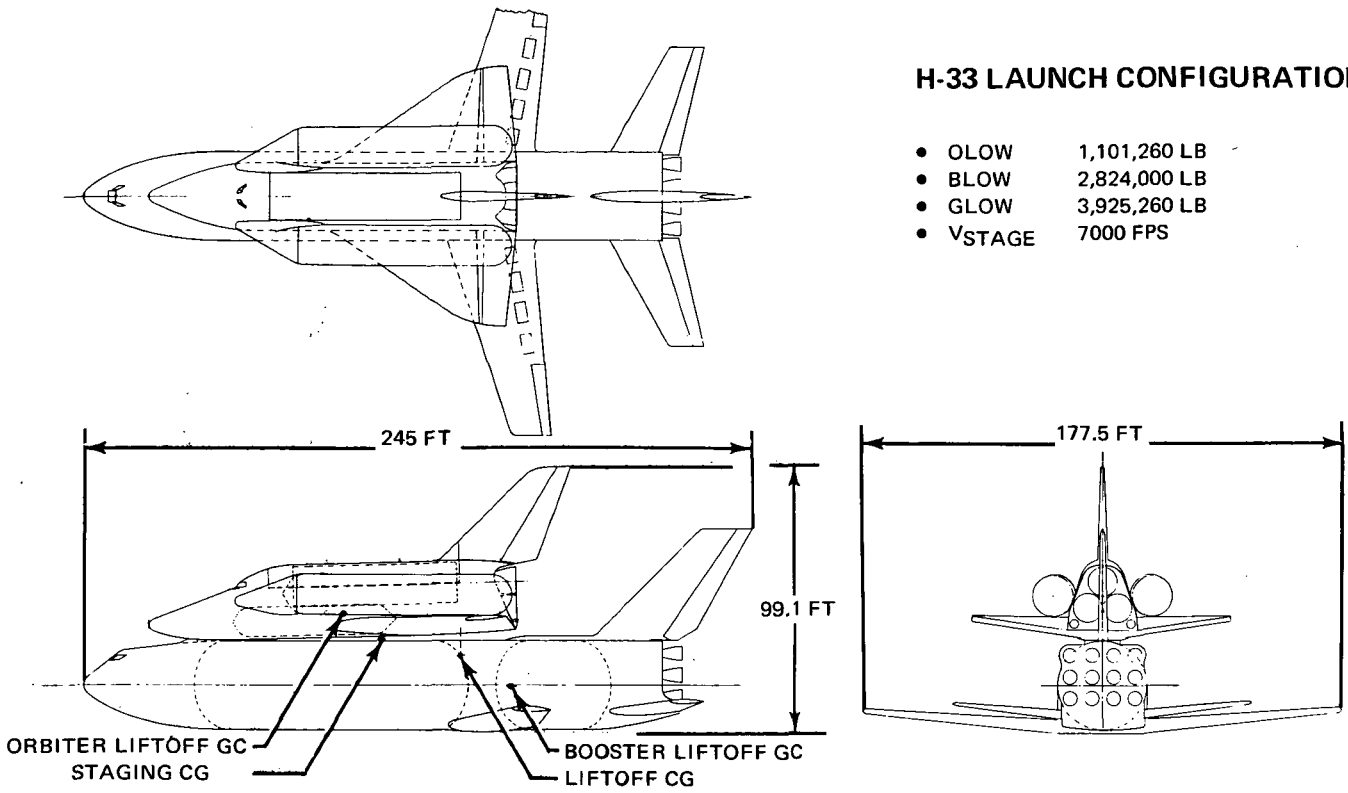
The ASSC study was conducted jointly by the Grumman Aerospace Corporation, the Boeing Company, and their associates. To assure consistency of results, Grumman and Boeing worked closely together in all areas. In general, Grumman concentrated on overall study management, orbiter design, analysis of mated configurations, and development test planning. Boeing concentrated on booster design, ground operations, and maintenance planning. The other team associates and their major areas of participation are shown in the accompanying figure.




The initial phase of the study was directed toward definition and comparison of promising alternatives to the fully reusable concept including stage-and-one-half, expendable first stages, and variants of the two-stage reusable system. This culminated in a configuration recommendation at the study mid-term point to pursue an External $LH_2$ Tank Orbiter/Heat Sink Booster configuration. The remainder of the study was devoted to generation of detailed design, operational, and cost data for the selected candidate such that meaningful comparisons with internal tanked orbiter/TPS booster configurations could be made.

During subsequent effort, both two and three-engined orbiters embodying the External Hydrogen Tank/Heat Sink Booster concept were compared to a representative internal hydrogen tank configuration. Results were reviewed by NASA in March and April, 1971. As an outgrowth of these reviews, Grumman/Boeing were authorized to emphasize study of a Three-Engined External Hydrogen Tank Orbiter/Heat Sink Booster utilizing 415K sea level thrust engines. It is this configuration, designated H-33, which forms the basis for the technical, cost, and programmatic documentation submitted in fulfillment of the ASSC contract.

As part of the contract effort, a detailed design and cost comparison was made between the H-33 and a conventional internal $LH_2$ tank orbiter/TPS booster designated G-3. Results of this comparison show the H-33 to be significantly lighter, simpler, and less costly than its internal tank counterpart. Gross liftoff weight is reduced by 30%, and wetted area is reduced by 16% and 30% on orbiter and booster, respectively. The highlights of the H-33 configuration and its operational characteristics are summarized on the following pages.




## H-33 LAUNCH CONFIGURATION

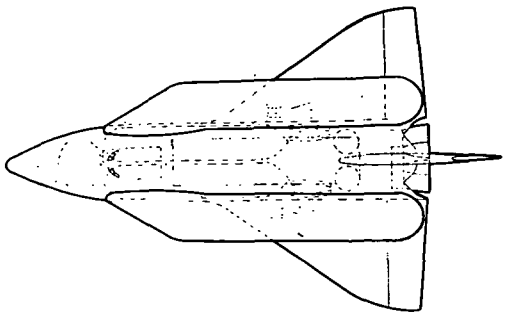
- OLOW 1,101,260 LB
- BLOW 2,824,000 LB
- GLOW 3,925,260 LB
- $V_{STAGE}$ 7000 FPS

The H-33 Orbiter and Booster are mated in a belly-to-back configuration via two centerline attach/separation points which span the booster $LH_2$ tank. Lateral mounting stability is provided by aft-mounted outboard pressure pads. Two hydraulically actuated mechanical linkages, recessed in the booster body to minimize the booster-orbiter air gap, provide positive separation at staging. A forward fairing between the vehicles significantly reduces interference heating.

Common 415,000 lb thrust (SL) engines are installed in orbiter and booster, which employ 3 and 12 engines, respectively. The engines are throttleable to 50% and gimbal to provide control during launch and insertion. The air breathing propulsion systems (ABPS) comprise the currently available JTF-22A-4 in both orbiter (4) and booster (8).

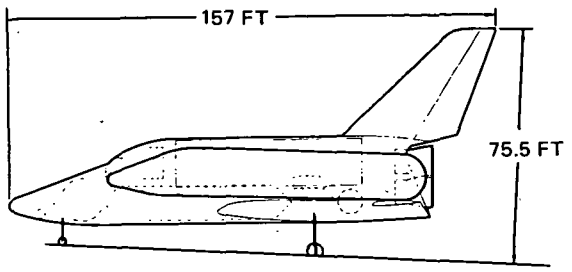
The more modest size and lower gross liftoff weight (GLOW) of the configuration is a product of the external $LH_2$ tank orbiter design concept:

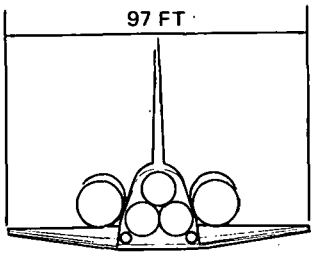
- The external $LH_2$ tanks permit high orbiter delta-V coupled with low core vehicle size and weight
- The improved orbiter structural efficiency causes the mated vehicle weight to optimize at a low staging velocity (7000 fps)
- The low staging velocity results in a low (227 n mi) booster flyback range, reduces booster size, and permits 100% Heat Sink Booster construction



## H-33 ORBITER CONFIGURATION

| | |
|---|---|
| PAYLOAD UP/DN (POLAR) | 40,000 LB |
| INJECTION WEIGHT (W/O TANKS) | 268,660 LB |
| INJECTION WEIGHT (W/TANKS) | 292,260 LB |
| LANDED WEIGHT | 241,172 LB |
| MAIN PROPELLANT | 809,000 LB |
| LIFTOFF WEIGHT | 1,101,260 LB |
| MAIN ENGINES, 3 @ $T_{VAC}$ | 477,000 LB |
| T/W | 1.30 |



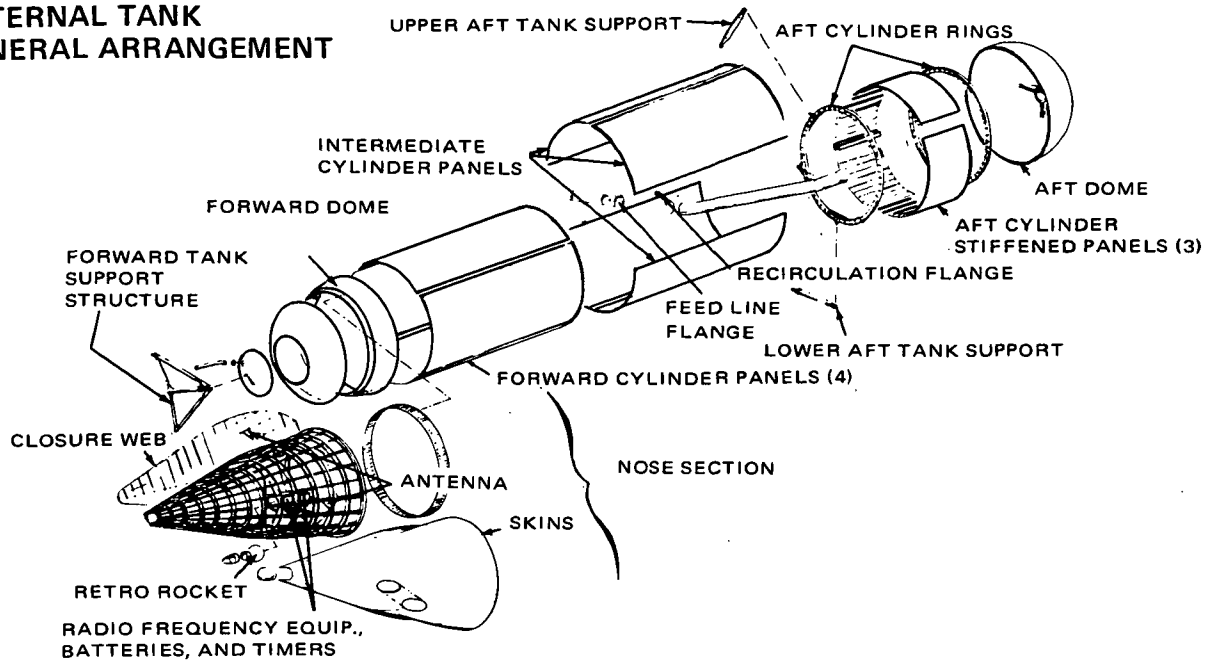




The H-33 Orbiter is a compact delta wing/centerline fin configuration carrying main propulsion $LH_2$ in two side-mounted jettisonable tanks. Tank nose fairings reduce drag and interference heating during launch. The rocket propulsion installation comprises: three 477,000 lb vacuum thrust engines (415K SL) for insertion; two 15,000 lb thrust RL-10 engines for on-orbit/de-orbit maneuvers; and thirty 1000 lb thrust ACPS engines for fail-op/fail safe attitude control during orbital operations and reentry.

Aerodynamic control is provided by full span elevons and a segmented split rudder which is flared ±30 deg for supersonic directional stability and for drag modulation (lower segment only) during landing. The vehicle meets the 1100 n mi cross-range requirement and is stable over the flight regime. Configuration design characteristics are:

- Constant body cross-section over 16 ft diameter x 65 ft long payload bay
- Payload bay position yields small in/out cg shift (0.7% body length)
- Air breather installation comprises two pairs of deployable JTF-22A-4 off-the-shelf engines; in/out cg shift 0.5% body length; removal yields two 5 x 10 x 13.75 ft compartments for alternate use
- Non-integral twin 11 ft D x 60 ft L oxidizer tanks are simply supported and removable for repair and refurbishment via the nose section manufacturing break
- 990 cu ft crew compartment houses four man crew plus EC/LSS, avionics and EPS. Direct access to payload bay via airlock.
- Thermal protection uses standoff insulated panels except for carbon/carbon on nose, leading edges, and elevon trailing edge
- Landing system comprises dual wheel nose and main gear plus twin 30 ft D drag chutes. Gear rotates aft for deployment; aero blowdown provides second-tier backup

## EXTERNAL TANK GENERAL ARRANGEMENT



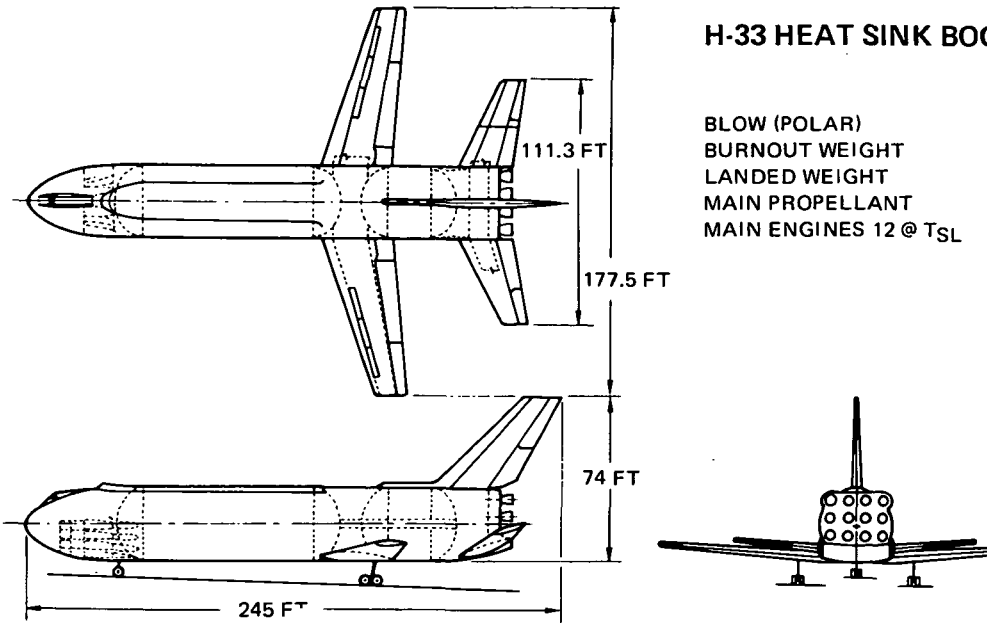

Each external tank is a 14.8 ft D cylinder with simple conical/hemispherical forward/aft end domes. LOA is 102 ft including the 17.6 ft aluminum allow sheet-frame-stringer nose fairing. The tank shell is a welded monocoque structure of 2219 aluminum alloy sheet, 0.057-in. thick between weld lands. $LH_2$ capacity each tank is 59,394 lb; dry weight is 10,349 lb/tank.

A 0.75-in. thick external layer of spray-on NOPCO BX250A foam provides cryogenic insulation. Spray-on Pirex 250 ablator, 0.1-in. thick, protects the tank inboard surface against interference heating. Nose fairing and strut thermal protection is afforded by an Avcoat 5026-39 ablative cover.

Attach struts are located at the forward and aft ends of the tank. Separation is effected by release of three marman-type clamps via triply redundant explosive bolts plus initiation of two pyrotechnic actuators, which thrust the tanks laterally with a total impulse of 1460 lb-sec/tank. All hardware is retained (no "shrapnel").

The redundant receiver decoders, timing circuits, and batteries used to initiate the tank de-orbit burn are located in the nose fairing together with the 10,000 lb thrust de-orbit SRM. A burn time of 7 sec imparts 200 fps de-orbit delta-V to the tank. Key points of this design approach are:

- Existing technology applicable: aluminum/$LH_2$ compatibility plus use of S-II spray-on foam insulation and ablator
- Simple fabrication: untapered cylinder, simple end caps, no integral webs
- Decoupled development from basic orbiter structure
- Volume growth potential with minimum impact
- Fracture mechanics/flaw growth issue avoided
- Reusable cryogenic insulation development issue avoided
- Post-flight $LH_2$ tank purging and inspection eliminated




## H-33 HEAT SINK BOOSTER

| | |
|---|---|
| BLOW (POLAR) | 2,824,000 LB |
| BURNOUT WEIGHT | 575,000 LB |
| LANDED WEIGHT | 520,000 LB |
| MAIN PROPELLANT | 2,249,000 LB |
| MAIN ENGINES 12 @ $T_{SL}$ | 415,000 LB |

FIG. 9.1-1 H-33 HEAT SINK BOOSTER CONFIGURATION (MODEL 979-124)

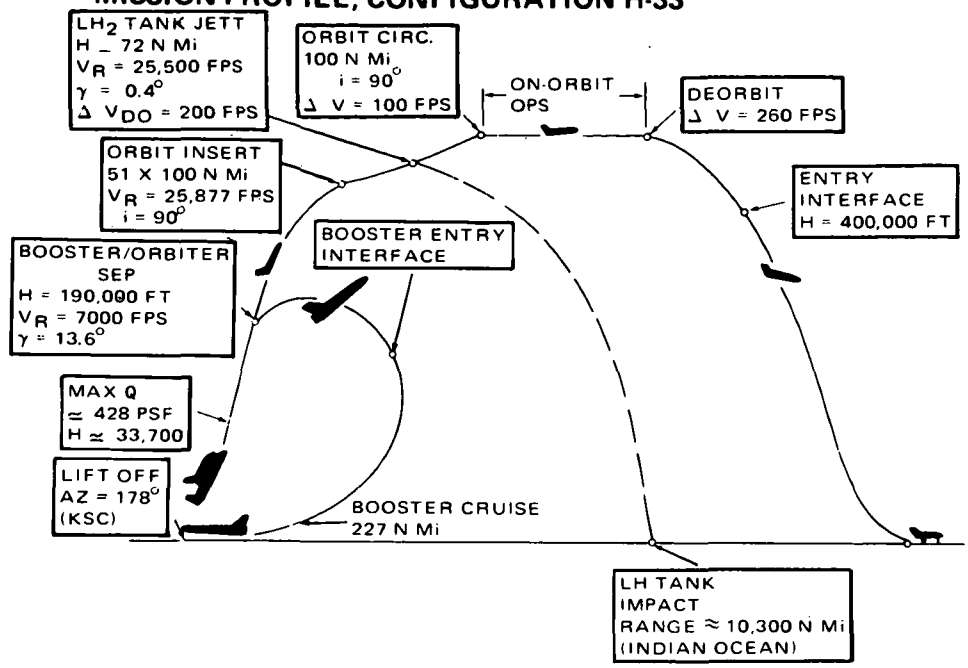
The H-33 booster is a conventional straight wing configuration powered by twelve 415 K lb SL thrust rocket engines plus eight air breathers for flyback. The 218 ft long x 33 ft diameter body contains a two-man crew compartment, buried air breathers with deployable inlets and recessing exit doors, primary propulsion tankage and engines, and the accessories/consumables required for its 60 minute mission.

Booster design employs 100% heat sink structure. The $LH_2$ tank is a 2219 aluminum alloy cylindrical shell with integral internal waffle stiffening and 70% elliptical end domes. Internally bonded PPO foam maintains initial $LH_2$ tank temperatures at -220°F and -100°F on heads and cylinder, respectively. The 2219 aluminum alloy $LO_2$ tank incorporates internal "T" stiffeners and anti-slosh baffles. Its aft location reduces fuselage structural weight, eliminates geysering, minimizes Pogo susceptibility, and accommodates straight-through passage of the wing carrythrough structure.

The wing and all-moving stabilizer are conventional two-spar aluminum alloy structure with titanium leading edges and control surfaces. Haynes 188 structure sustains plume impingement heating on the fin leading edge at orbiter separation. Flight attitude control utilizes boost engine gimballing during launch, 34 ACPS thrusters during coast and entry, and activation of control surfaces for flyback. Significant design characteristics are:

- 100% heat sink construction eliminates TPS panel development and refurbishment. Smooth surfaces minimize slot/protuberance heating
- Saturn technology and tooling are directly applicable to tank design
- $LH_2$ leaks are readily detectable (visible frost ring)
- Air breather: booster accommodates JTF-22A-4 or the B-1 engine. Development status, commonality, and availability dictates JTF-22A-4
- Aerodynamic configuration: stable/controllable through flight regime; accommodates 30 kt cross wind at landing

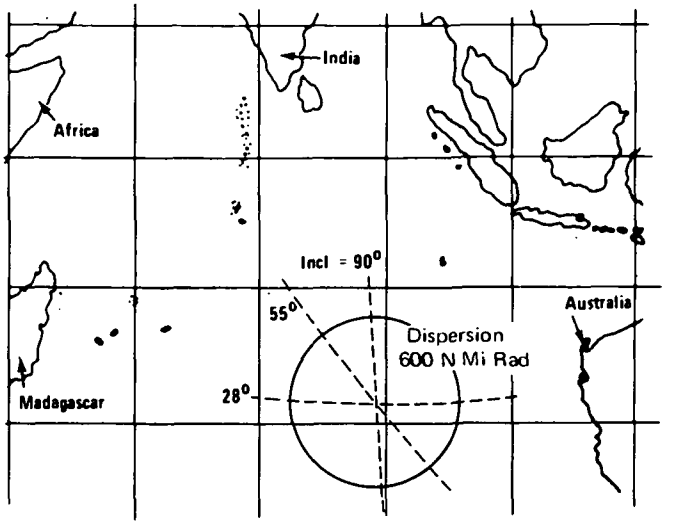
## MISSION PROFILE, CONFIGURATION H-33




A typical mission profile for the H-33 configuration is shown above. Significant events are summarized below, using values representative of a polar launch.

- Vehicle liftoff is accomplished vertically with an initial T/W ratio of 1.27. Vehicle GLOW is 3.93 M lb
- Maximum dynamic pressure (q) of 428 psf is encountered at an altitude/velocity of 33,700 ft/1051 fps, 76.2 sec after liftoff
- Separation occurs 181.4 sec after liftoff at an altitude/velocity of 190,000 ft/7,000 fps. Flight path angle and q are 13.6 deg and 18.4 psf, respectively
- Booster entry/flyback includes coast to 235,000 ft apogee, trim to 60 deg entry alpha, initiation of 90 deg bank at q max (111 psf), start transition at 30,000 ft (wings level) and start 227 n mi flyback at 16,000 ft. Maximum normal load factor is 3.5 g; approach/landing speeds are 161/155 kt, respectively
- Orbiter insertion into a 51 x 100 n mi orbit requires a burn time of 275.5 sec with an initial T/W of 1.3. Insertion velocity is 25,877 fps
- External tank jettison occurs 20 min after orbiter burnout at an altitude/velocity of 72 n mi/25,500 fps. Tanks are separated at an orbiter attitude of 30 deg nose up; 20 sec later ignition of the de-orbit SRM's is initiated via rf link; impact is 10,300 n mi downrange at 30 deg South Lat/90 deg East longitude (Indian Ocean)
- Orbiter entry is initiated with a 130 sec burn oriented 0 deg to the local horizontal. Entry alpha is 27 deg. The vehicle is controlled to thermal boundaries down to 1/2 circular velocity with subsequent control to a latitude/longitude target. Maximum q/normal load factor are 260 psf and 1.28 g, respectively. Full aero surface control is initiated at M = 4; approach/touchdown speeds are 240/180 kt, respectively.

## EXTERNAL TANK ENTRY DISPERSIONS



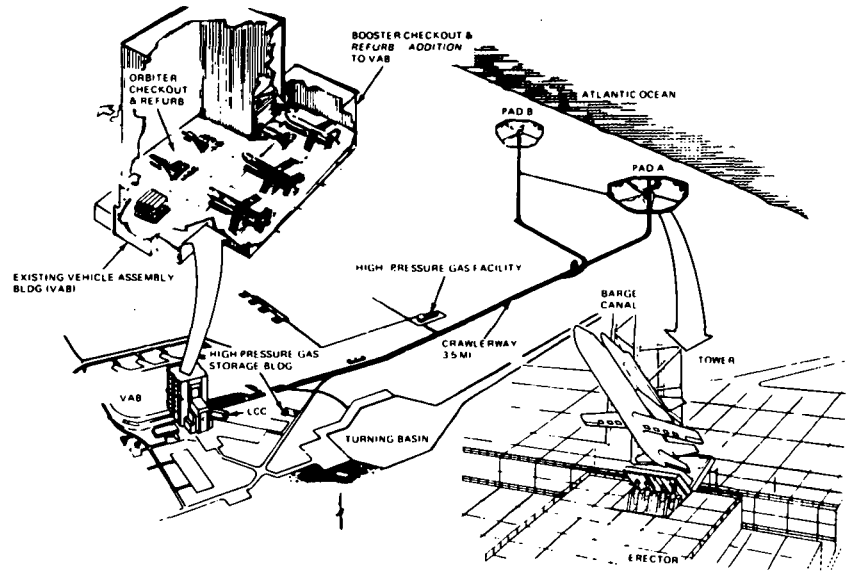

Impact areas and dispersions predicted for the baseline external hydrogen tank disposal system are shown above for KSC launches. The impact zone for KSC reference missions is confined to a single region in the South Indian Ocean, approximately 1500 n mi west of Australia. Impact for polar and retrograde launches from WTR occurs in the Pacific ocean at 60 deg S latitude, north of the Antarctic land mass.

No attitude control system is required on the tank. Dispersion analyses considering variations in orbiter alignment, tank cg location, attitude, and separation/de-orbit system hardware characteristics show an in plane error of 6.5 deg in the de-orbit velocity vector. Resulting impact dispersions of surviving particles for a tumbling tank with a breakup altitude of 300,000 ft are ± 600 n mi downrange, ± 18 n mi crossrange.

Predicted ship traffic densities for 1980 indicate that four ships, out of a possible 29,000 at sea, will be in the approximately 40,000 sq mi elliptical impact area. For any mission, the resulting probability of any one particle impacting a ship is less than $1 \times 10^{-7}$. Summarizing the characteristics of the disposal system:

- External $LH_2$ tank materials and design approach encourage tank breakup and fragment burnup during entry
- Selected impact regions are remote from high density shipping lanes
- Impact dispersions are acceptable without active tank attitude control

## GROUND OPERATIONS




Orbiter and booster are initially barged from the Michoud assembly area with wings and tail surfaces disassembled. Final assembly is accomplished in the vertical assembly building (VAB) at KSC. Subsequent ground operations encompass all maintenance, checkout, mating, and launch operations required on booster, orbiter, and payload from touchdown through launch of the next mission. The ground operations concept is directed toward eventual achievement of "airline type" operating practices utilizing onboard checkout/monitoring provisions. Key events in the operations cycle are:

- Subsystem and system checkout takes place in the VAB. Subsystem tasks comprise visual inspection, scheduled/unscheduled maintenance, and hardware functional checks. System verification of orbiter and booster will be performed to ensure preservation of interface compatibility. Orbiter system testing will be preceded by mating of external $LH_2$ tanks

- Vehicle mating will be accomplished in a horizontal attitude by positioning the orbiter on the booster via a two-point suspension two-crane operation. Mating and interface verification will be followed by payload installation

- Transfer to the pad will be accomplished by a 747-type tug, which tows the shuttle on the booster landing gear to the pad and positions it on the integral holddown/erector. The holddown clamps are secured to the booster, and the vehicle erected to the launch position

- Final checkout and launch comprises propellant loading, crew and passenger boarding, final status checks by onboard avionics, system pressurization, and switch to internal power. Booster main engines are ignited; upon verification of thrust buildup, the holddown arms are released for liftoff

## H-33 ALTERNATE MISSION CAPABILITY (VEHICLES SIZED FOR 40K PAYLOAD TO POLAR ORBIT)

| MISSION | OMS DELTA-V REQUIRED* (FPS) | | PAYLOAD CAPABILITY (K LB) |
|---|---|---|---|
| | NOMINAL | ABORT ** | |
| POLAR - 90 DEG | 810 | 795 | 40 |
| RESUPPLY - 55 DEG | 1690 | 720 | 26.2 |
| DUE EAST -28.5 DEG | 1190 | 695 | 65.7 |

* ORBITER CARRIES MAXIMUM OF MISSION OR ABORT OMS DELTA-V

** INCLUDES 120 FPS FOR ENTRY ACPS MANEUVERING

Shuttle requirements specify the following orbiter payload capability for the three reference missions:

- Polar 100 n mi Orbit: 40 K lb up and down (no ABPS)
- $55^{o}$ Inclination 270 n mi Orbit: 25 K lb up and down (with ABPS)
- Due East 100 n mi Orbit: 65 K lb up, 40 K lb down (no ABPS)

Also required is orbiter once-around abort capability in the event of an inoperative main engine at separation. The abort is accomplished by operating the remaining engine(s) at emergency power in conjunction with a parallel on-orbit maneuvering system (OMS) burn during insertion, followed by a passive entry and return to site.

The capability afforded by the three-engined H-33 configuration in meeting both payload and abort requirements is shown in the above table, which summarizes payload capacity and OMS nominal and abort delta-V requirements for the three reference missions. The following characteristics are noted:

- H-33 provides a close payload match for all three reference missions. The vehicle is sized by the polar mission 40 K lb payload requirement. As indicated in the above table, the payload capability for the remaining reference missions corresponds closely to the requirements
- H-33 OMS propellant quantity is not penalized by abort requirements. This is a consequence of the three-engined installation, which reduces the OMS abort requirement for the engine-out case below the OMS delta-V required by the nominal missions

## TRADE STUDY SUMMARY

| ENGINEERING | | MANUFACTURING | 12 |
|---|---|---|---|
| • STRUCTURES/TPS | 20 | GRND OPERATIONS | 3 |
| • G&C/AERO/THERMO | 21 | TEST | 2 |
| • PROPULSION | 8 | | |
| • AVIONICS/ELECTRICAL | 5 | TOTAL - 82 | |
| • ECLSS/CREW ACCOMM | 7 | | |
| • PAYLOAD INTEGR/SAFETY | 3 | | |
| • VEH OPTIMIZATION (V STAGE) | 1 | | |

Eighty-two major tradeoff studies have been performed in support of the External $LH_2$ Tank Orbiter/ Heat Sink Booster system definition, including 65 in engineering, 12 in manufacturing, and 5 in operations and test. While they are by no means an exhaustive collection of studies, they have served to provide a reasonable degree of system optimization and maturity, particularly with respect to vehicle design characteristics, where the greatest emphasis has been placed.

Certain significant factors have not as yet been subjected to tradeoffs, but have been accepted as groundrules: these include the payload and mission performance requirements, the operational program schedule and traffic model, the use of KSC as the launch site, and the approach to transonic/supersonic flight test prior to FMOF.

Of the total number of tradeoff studies tabulated above, 58 have been formally published prior to completion of the study. The remainder are documented in the ASSC final reports.

## SYSTEM SUMMARY COMPARISON - POLAR MISSION

| | H-33: 3 ENG EXT TK | | G-3:2 ENG INT TK | | G-3 VS H-33: DELTAS | |
|---|---|---|---|---|---|---|
| | ORB. | BOOST. | ORB. | BOOST. | ORB. | BOOST. |
| WEIGHTS, LB | | | | | | |
| • GLOW | 3,925,260 | | 5,240,920 | | 1,315,360 | |
| • OLOW/BLOW | 1,101,260 | 2,824,000 | 938,280 | 4,302,640 | -162,980 | 1,478,640 |
| • INJECTION PROP | 809,000 | 2,249,000 | 632,275 | 3,348,470 | -176,725 | 1,099,470 |
| • DRY WT: STAGE | 197,238 | 494,870 | 220,135 | 798,448 | 22,897 | 303,578 |
| TANKS (2) | 20,698 | - | - | - | - | - |
| TOTAL | 712,806 | | 1,018,583 | | 305,777 | |
| DIMENSIONS | | | | | | |
| • LGTH OVERALL, FT | 157 | 245 | 173 | 296 | 16 | 51 |
| • SPAN, FT | 97 | 177.5 | 101.7 | 221.3 | 4.7 | 43.8 |
| • WETTED AREA, $FT^2$ | 17,930 | 33,794 | 21,350 | 47,767 | 3,420 | 13,973 |
| PROPULSION | | | | | | |
| • PRIMARY: NO. ENG/ THRUST | 3/477 K (VAC) | 12/415 K (SL) | 2/632 K (VAC) | 13/550 K (SL) | - | - |
| • AIR BREATHERS | JTF-22A-4(4) | JTF-22A-4(8) | JTF-22A-4(4) (2 W/AB) | B-1 (10) | | |
| PERFORMANCE | | | | | | |
| • STAGING VELOCITY, FPS | 7,000 | | 9,750 | | 2,750 | |
| • ORB. IDEAL DELTA-V, FPS | 19,600 | - | 16,538 | - | -3,062 | - |
| • FLYBACK RANGE, NM | | 227 | - | 368 | | 141 |

The purpose and intent of the ASSC study has been to define and develop a promising alternative to the fully reusable internal tank orbiter/TPS booster configuration, to a depth which permits meaningful comparison of design concepts. The study has culminated in a detailed definition of the H-33 External Tank Orbiter/Heat Sink Booster configuration, which has been compared on technical, operational, and cost bases to its counterpart, the internal tank orbiter/TPS booster G-3 configuration.

The above table lists major characteristics of each vehicle in sufficient detail to contrast key differences. Weight and performance values shown reflect the polar mission, which sized both vehicles. The comparison clearly identifies the advantages of the Three-Engined External Tank Orbiter configuration:

- *Higher Orbiter Delta-V:* *H-33 provides 3,000 fps more insertion delta-V at an all-up (tanks included) dry weight 2200 lb less than G-3.* This characteristic results in system weight optimization at a reduced staging velocity, which benefits booster design as cited below

- Lower Staging Velocity: The H-33 7000 fps staging velocity is 2750 fps less than that of G-3. The resultant reduction in boost propellant and flyback range yields a smaller (delta gross weight 1.48 M lb) booster and permits full exploitation of the heat sink approach to booster design. Booster TPS panel design, development, and operational refurbishment are thereby avoided

- Reduced Dry Weight: H-33 is 306,000 lb (30%) less than G-3 in all-up dry weight, with an attendant decrease in overall dimensions and wetted area as tabulated above. This characteristic eases handling and erection requirements as well as inspection and refurbishment of vehicle outer surfaces

- Lower GLOW: H-33 gross liftoff weight is 1.32 M lb (25%) less than G-3. Substantially less boost/injection propellant (922 K lb) is required; liftoff is accomplished with twelve 415 K lb thrust engines as opposed to thirteen 550 K lb thrust engines

As the above summary indicates, application of the external $LH_2$ tank approach to shuttle design results in orbiter and booster configurations which are smaller, lighter, simpler, and hence less costly than their internal tank counterparts.

* * *

The foregoing introduction has provided a brief description of the Grumman/Boeing External $LH_2$ Tank Orbiter/Heat Sink Booster Shuttle configuration, its operational characteristics and its capability. The following page contains a Study Volume Guide, which identifies the final documents submitted in fulfillment of the ASSC contract.

Also listed are additional documents developed under the Grumman/Boeing Bid and Proposal effort currently underway in anticipation of proposals for a Space Shuttle System industry competition. These documents represent an interim stage in the Bid and Proposal preparation effort, and as such, are submitted at this time for NASA's information only.

## ASSC STUDY VOLUME GUIDE

| A. ASSC Contract Documentation | Vol I.D | Grumman Doc. No. | NASA Doc. No. |
|---|---|---|---|
| 1) Final Report | | | |
| Part I Executive Summary | | B35-43RP-11 | MSC-03809 |
| Part II Technical Summary | | B35-43RP-12 | MSC-03810 |
| Vol. I Shuttle Definition | A | | |
| Vol. II Orbiter Definition | B | | |
| Vol. III Booster Definition | C | | |
| Part III Engineering and Development Plan | | B35-43RP-13 | MSC-03811 |
| Vol. I Shuttle System | D | | |
| Vol. II Orbiter Vehicle | E | | |
| Vol. III Booster Vehicle | F | | |
| Part III Operation Plan | G | B35-43RP-14 | MSC-03812 |
| Part III Program Cost and Schedule Plan | H | B35-43RP-15 | MSC-03813 |
| 2) Detail Mass Properties Report | | B35-43RP-16 | MSC-03814 |
| Vol. I Orbiter/Booster Mass Properties | S | | |
| Vol. II Orbiter Weight Substantiation | T | | |
| Vol. III Booster Weigh Substantiation | U | | |
| B. Shuttle Bid and Proposal* Documentation | | | |
| 1) Program Management Plan | J | 552-43RP-1 | |
| 2) Manufacturing Plan | K | 552-43RP-2 | |
| 3) Integrated Test Plan | L | 552-43RP-3 | |
| 4) Facilities Plan | M | 552-43RP-4 | |
| 5) Logistics and Maintenance Plan | N | 552-43RP-5 | |
| 6) Quality Assurance Plan | P | 552-43RP-6 | |
| 7) Reliability and Maintainability Plan | Q | 552-43RP-7 | |
| 8) Safety Plan | R | 552-43RP-8 | |

* Submitted for NASA's information only; not for dissemination as part of ASSC Study "data dump" to industry.

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PROPULSION

Section 4

# PROPULSION

The objective of the engineering and development program is to attain Apollo high reliability, safety, and mission success at substantially lower cost. We believe that this objective can be achieved because: (a) the data and history of the Apollo program is available for use as a base for planning the shuttle program, and (b) the shuttle is reusable, permitting the use of many standard aircraft techniques.

In formulating the development logics for the main, reaction control, orbit maneuvering, and airbreathing propulsion subsystems we have selected those features from the Apollo and aircraft programs which have proven to be most beneficial and we have eliminated those which did not stand the scrutiny of retrospective analysis.

Some of the more significant features are:

- During the early design phase, emphasis is placed on defining the real hardware requirements before committing to procurement. Elimination of active systems, desensitizing the overall design to component parameters, and formulation of contingency plans are key elements
- Rigorous design reviews of materials, processes, and safety factors are planned before committing to fabrication
- More effort is programmed for development test planning. Extensive pre-test analysis to determine the critical environments, to combine tests, and to define the test objectives will result in a lesser number of tests and test hardware being required
- Formal qualification of all components is planned to reveal latent design deficiencies. These problems can be solved best at the component level

- Subsystem verification and certification tests are at the highest level of assembly practicable. Analysis is used to aid verification. Integrated test objectives considering engineering, manufacturing, quality, reliability, and operations are included. Software, operational GSE, and final procedures are used early to assure compatibility

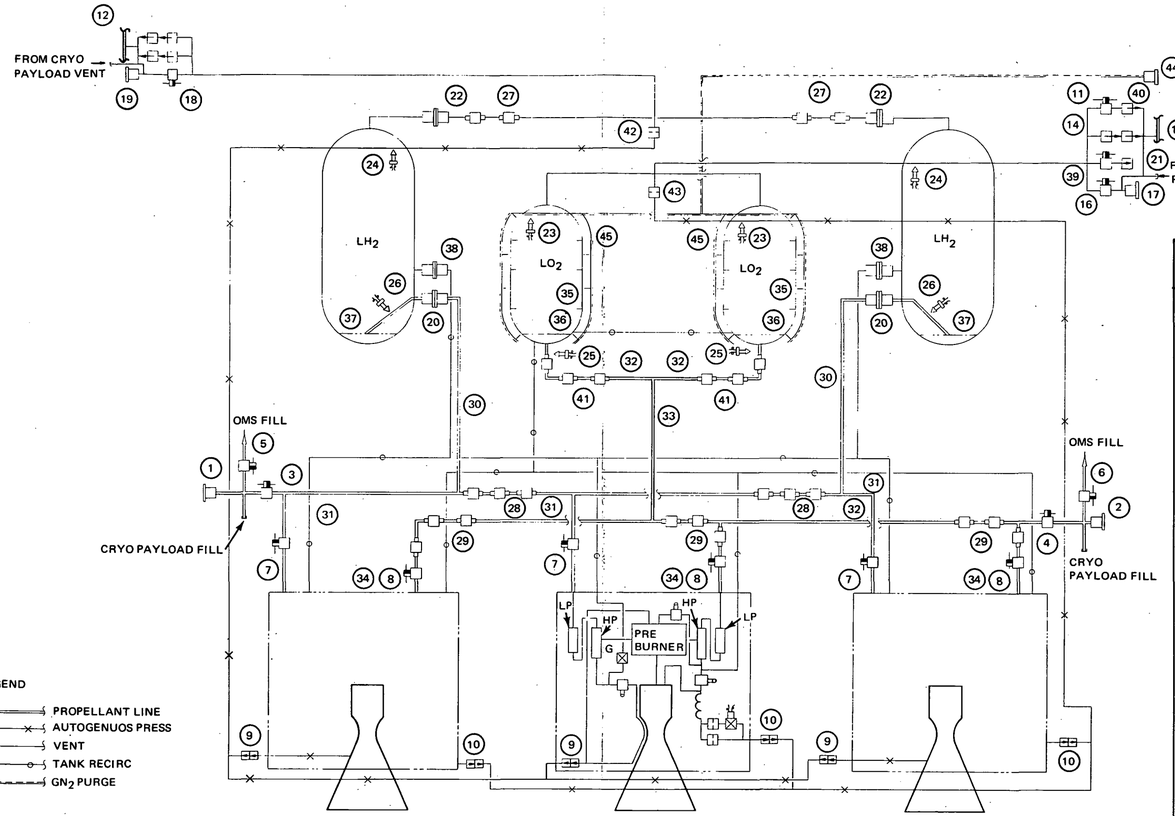
- Component acceptance tests at the subcontractor encompasses all functional and passive testing to insure that deliverable hardware meets the vehicle requirements. This permits the use of "selective pre-installation tests" for revalidation/reinspection. Grumman's current space and aircraft programs provide much statistical data to support the selection of components for PIT. As an example, a preliminary review of historical data shows that pre-installation tests are cost effective for such components as pressure relief and quad-check valves and are not required for disconnects and filters. Final selection of components for PIT is planned based on performing a complete review of historical data together with component analysis of design and assembly

## 4.1 MAIN PROPULSION SUBSYSTEM (MPS)

### 4.1.1 SUBSYSTEM DESCRIPTION

The MPS provides the thrust to accelerate the orbiter from booster separation to earth orbit injection. The basic subsystem sections shown schematically in Fig. 4.1-1 are the cryogenic propellant storage tanks, the propellant pressurization and feed system, and three turbopump-fed $LO_2/LH_2$ rocket engines. Each of the engines is identical to the booster engines with the exception that the orbiter engines use a two-position nozzle extension to achieve higher performance at altitude.

Ground-supplied helium is used for pre-launch pre-pressurization. In flight, the respective propellant tanks are pressurized by $GH_2$ and $GO_2$ tapped from the engines. Tank pressure is controlled by a dual-level continuous flow system. Vehicle-supplied helium is used for pneumatic control of system and engine components and purge requirements. Pneumatic operated pre-valves are installed in each $LO_2$ and $LH_2$ engine feedline to effect feed system isolation of engines during on-orbit operations or emergency engine failure conditions.




H-33 ORBITER - MAIN PROPULSION - MAJOR COMPONENT LIST

| NUMBER | COMPONENT/DESCRIPTION | LINE SIZE | QTY/ VEH | UNIT WEIGHT, LB | REMARKS |
|---|---|---|---|---|---|
| 1 | $LH_2$ FILL DISCONNECT-SELF SEAL FLT | 6.0 | 1 | 10 | |
| 2 | $LO_2$ FILL DISCONNECT -SELF SEAL FLT | 6.0 | 1 | 10 | |
| 3 | $LH_2$ FILL VALVE - ISOLATION | 6.0 | 1 | 31 | |
| 4 | $LO_2$ FILL VALVE - ISOLATION | 6.0 | 1 | 31 | |
| 5 | $LH_2$ OMS - FILL VALVE - ISOLATION | 2.5 | 1 | 10 | |
| 6 | $LO_2$ OMS - FILL VALVE - ISOLATION | 2.5 | 1 | 10 | |
| 7 | $LH_2$ PRE VALVE | 12.0 | 3 | 96 | |
| 8 | $LO_2$ PRE VALVE | 10.0 | 3 | 68 | |
| 9 | $H_2$ CHECK VALVE - SERIES | 1.0 | 3 | 10 | |
| 10 | $O_2$ CHECK VALVE - SERIES | 1.0 | 3 | 10 | |
| 11 | $O_2$ SHUT-OFF VALVE - RELIEF | 3.0 | 1 | 12 | |
| 12 | $H_2$ NON PROPULSIVE VENT | TBD | 1 | TBD | |
| 13 | $O_2$ NON PROPULSIVE VENT | TBD | 1 | TBD | |
| 14 | $O_2$ RELIEF VALVE - HIGH PRESS SERIES | 3.0 | 1 | 28 | |
| 15 | $H_2$ RELIEF VALVE - HIGH PRESS SERIES | 3.0 | 2 | 28 | |
| 16 | $O_2$ SHUTOFF VALVE - GND PRESS | 3 | 1 | 12 | |
| 17 | $O_2$ PRESS DISCONNECT - S.S. FLIGHT | 3 | 1 | 5 | |
| 18 | $H_2$ SHUTOFF VALVE - GND VENT & PRESS | 10.0 | 1 | 68 | |
| 19 | $H_2$ VENT/PRESS DISCONNECT - S.S. FLIGHT | 10.0 | 1 | 22 | |
| 20 | $LH_2$ FEED DISCONNECT - DROP TANK | 14.0 | 2 | 26.5 | |
| 21 | $O_2$ CHECK VALVE - FLAPPER VENT | 10.0 | 1 | 10 | |
| 22 | $H_2$ VENT/PRESS DISCONNECT - DROP TANK | 6.0 | 2 | 12.0 | |
| 23 | $LO_2$ POINT SENSOR ASSY - LOADING | N/A | 2 | 3 | |
| 24 | $LH_2$ POINT SENSOR ASSY - LOADING | N/A | 2 | 3 | |
| 25 | $LO_2$ POINT SENSOR ASSY - LOW LEVEL | N/A | 2 | 3 | |
| 26 | $LH_2$ POINT SENSOR ASSY - LOW LEVEL | N/A | 2 | 3 | |
| 27 | $H_2$ BALL JOINTS - VENT/PRESS | 6.0 | 4 | 8.5 | |
| 28 | $LH_2$ BALL JOINTS - ENG FEED | 12.0 | 6 | 40 | |
| 29 | $LO_2$ BALL JOINTS ENG FEED | 10.0 | 9 | 26 | |
| 30 | $LH_2$ VACUUM JACKETED LINE | 14 | 2 | TBD | TK TO MANIFOLD |
| 31 | $LH_2$ VACUUM JACKETED LINE | 14-12 | 3 | TBD | MANIFOLD TO ENG |
| 32 | $LO_2$ LINE | 12 | 2 | TBD | TK TO MANIFOLD |
| 33 | $LO_2$ MANIFOLD LINE | 17 | 1 | TBD | MANIFOLD |
| 34 | $LO_2$ LINE | 14-10 | 3 | TBD | MANIFOLD TO ENG |
| 35 | $LO_2$ SLOSH BAFFLES | N/A | 6 | TBD | |
| 36 | $LO_2$ ANTI-VORTEX BAFFLES | N/A | 2 | TBD | |
| 37 | $LH_2$ ANTI-VORTEX BAFFLES | N/A | 2 | TBD | |
| 38 | $LH_2$ RECIRC DISCONNECT - FLT | 3 | 2 | 8 | |
| 39 | $O_2$ VENT SHUT-OFF ISOLATION | 10 | 1 | 68 | |
| 40 | $O_2$ RELIEF VALVE - LOW PRESS | 3.0 | 1 | 19 | |
| 41 | $LO_2$ BALL JOINTS | 12.0 | 6 | 40 | |
| 42 | $H_2$ ORIFICE | 1.0 | 1 | TBD | |
| 43 | $O_2$ ORIFICE | 1.0 | 1 | TBD | |
| 44 | $GN_2$ GROUND PURGE DISCONNECT - NON-SEALING | 1.5 | 1 | 1.5<br>125 | |
| 45 | $LO_2$ TANK PURGE MANIFOLD | | | TBD | |

Fig. 4.1-1 Orbiter Main Propulsion



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## 4.1.2 LOGIC NARRATIVE

Design and development of the MPS will depend heavily upon the analytical tools presently on hand at Grumman. These will be augmented by simulator computer programs developed during the program. Development testing will be conducted at the component and subassembly level and in conjunction with the single engine test program on the GFE main rocket engine.

All development tests and analytical programs for the MPS will be geared to quickly define and resolve design problems. Special emphasis is placed on the following design issues by providing alternate design approaches for minimizing system development risk impact.

- Space shuttle main engine - $I_{sp}$ effects
  - Consider oversize propellant tanks
- Tank pressurization
  - Increase feed line size to lower tank pressure
  - Provide dual $O_2$ heat exchangers
  - Raise gas temperature on $O_2$ side
- Pre-start conditioning
  - Increase size of electric motor on engine fuel booster pump to increase fuel flow rate
  - Consider electric pump drive for $LO_2$ system to increase flow rate, if natural convection system is deficient
- $LH_2$ tank line disconnects
  - Consider alternate design concepts such as pyrotechnic actuators and mechanical attachment clamps
- Tank expulsion efficiency
  - Alternate design provisions for tank outlets
  - Ready adaptability to increasing $LH_2$ tank size

As shown on the logic chart (Fig. 4.1-2), early definition of component hardware is necessary to provide a basis for all interface information and early determination of hardware commonality. Spacecraft systems design and software (computer program) inputs will be time-phased to lead this activity. Grumman's experience with LM development points out the need for early resolution of system interaction effects by means of preliminary development testing (DFT) and maximum use of software tools (computer math models). This effort will take approximately 15 months from go-ahead (Fig. 4.1-3) and will allow sufficient analysis and review of subcontractor proposals for making suitable selection awards for hardware.

The SSME requires timely resolution of all interface and system development problems. Grumman's experience with the weapons system integration board on the F-14 program will greatly benefit the shuttle effort in the close support required for the SSME. Engines specifically designed and built for a program require complete ready agreements between the engine manufacturer and the vehicle manufacturer in all areas of performance and interface conditions. Grumman proposes that all engine changes be coordinated between engine and vehicle manufacturer by the establishment of a space shuttle integration board for timely resolution of changes and providing a single recommendation to NASA for approval.

Grumman's close support to the main engine development program will permit timely update to system integration computer programs. In addition, early feed system data and gimbal actuator/engine interactions will be obtained through the use of vehicle feed lines and gimbal actuators during the single engine development test program.

Feed and pressurization system design parameters will be closely monitored to keep abreast of engine development considerations. Accordingly, production of all long lead hardware and systems will be scheduled subsequent to completing major DFT requirements for the spacecraft propulsion system and the SSME.

Subscale testing, utilizing transparent propellant tanks, will define the need for slosh baffles. The slosh test data and data from tank outflow tests will be used to design the slosh baffles (if needed) and the anti-vortex baffles. Verification of the slosh and outflow math models will also be obtained from these tests.

Early feed system dynamic data at nominal and off-nominal conditions will be obtained during cold-flow tests on feed line subassemblies. This data, in combination with the feed system/engine pump compliance data obtained from the single engine development testing, will provide inputs to the POGO analysis. The dynamic response of the MPS structures obtained from the ground vibration survey (GVS) on Flight Vehicles No. 1 and No. 2 will provide the final input required to perform a preliminary POGO analysis. It is expected that the preliminary POGO analysis will provide the required confidence to eliminate the need for dynamic response testing. The final POGO analysis will be performed using the feed system compliance data obtained during the PTA tests and the pump compliance data from the engine qualification program.

The main propulsion subsystems will be certified by testing the propulsion test article (PTA). Grumman proposes that the PTA be of flight-weight structure using flight-weight propellant lines, oxidizer tanks, and heavyweight hydrogen tanks. The use of flight weight structure in lieu of heavyweight is for cost-effective considerations, permitting this vehicle to be recycled at the conclusion of the test program for updating as Flight Vehicle No. 4. As a flight weight vehicle, the PTA is handled as a full-up production propulsion subsystem for test and ground service checkout activation.

The MPS certification test program may be performed at either KSC or MTF, assuming facility/GSE availability. PTA testing at MTF will permit greater flexibility for scheduling the test program with no impact to flight vehicle/facility launch preparations. However, instituting a propulsion test program at KSC will provide a test vehicle for KSC activation and checkout for the flight test program.

The PTA will provide data to update engine, GSE, and subsystem ICD requirements. Production-type hardware will be installed on the PTA to prototype a main propulsion feed system for system integration tests. It is proposed that all certification tests with this article be performed using flight vehicle interfaces and equipment wherever possible. A series of propellant cold flow tests will be performed in this phase to verify propellant loading control accuracy, propellant management, and engine inlet propellant conditions. Completion of all normal and malfunction certification tests during this phase provides the basis for the next phase of PTA testing - hot fire engine tests. The PTA test schedule is

consistent with the delivery of a set of SSME for the PTA clustered engine firing to be performed in this phase. Since, as stated above, it is expected that dynamic response testing will not be required, engine firing duration will be short (approximately 10 seconds). However, sufficient propulsion data for engine system operation during transient and steady state conditions will result. Sea level and altitude engine test data, as determined by the engine manufacturer's testing, will be used to iterate system tests to provide main propulsion certification for flight.

Compatibility of flight-type MPS/engine controls and the onboard checkout and monitoring system (OCMS) will also be demonstrated during the PTA testing. Use of flight-type APU's and gimbal actuators will verify their compatibility with the clustered engines. The MPs functional block diagram is shown in Fig. 4.1-4.

### 4.1.3 COMPUTER PROGRAM

The following computer programs are now available as analytical tools to help develop the MPS:

- Pressurization development program
- Propellant management program
- Stratification program
- Subsystem parametric optimization program
- Restart conditioning program

The following computer programs are considered necessary for design development of the MPS and will be developed during the design/development phase of the SS program:

- Propellant utilization program
- Feed system dynamics program
- Engine steady state simulation (NASA/Engine contractor supplied)
- Engine transient simulation (NASA/Engine contractor supplied)
- Flight prediction program
- Component test data reduction program

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- PTA data reduction program
- Flight data reduction program
- Propellant allotment program
- Slosh and outflow prediction program
- MPS/engine controls program
- Pre-pressurization development program

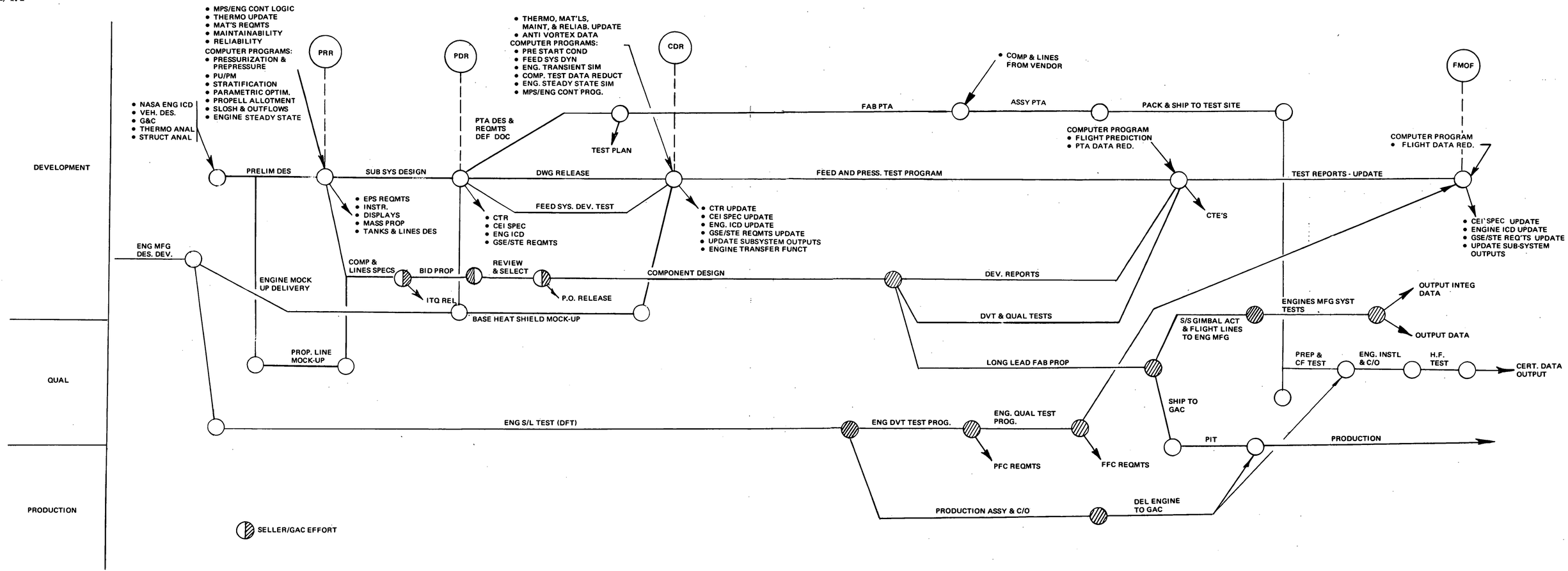


Fig. 4.1-2 Main Propulsion Logic Network



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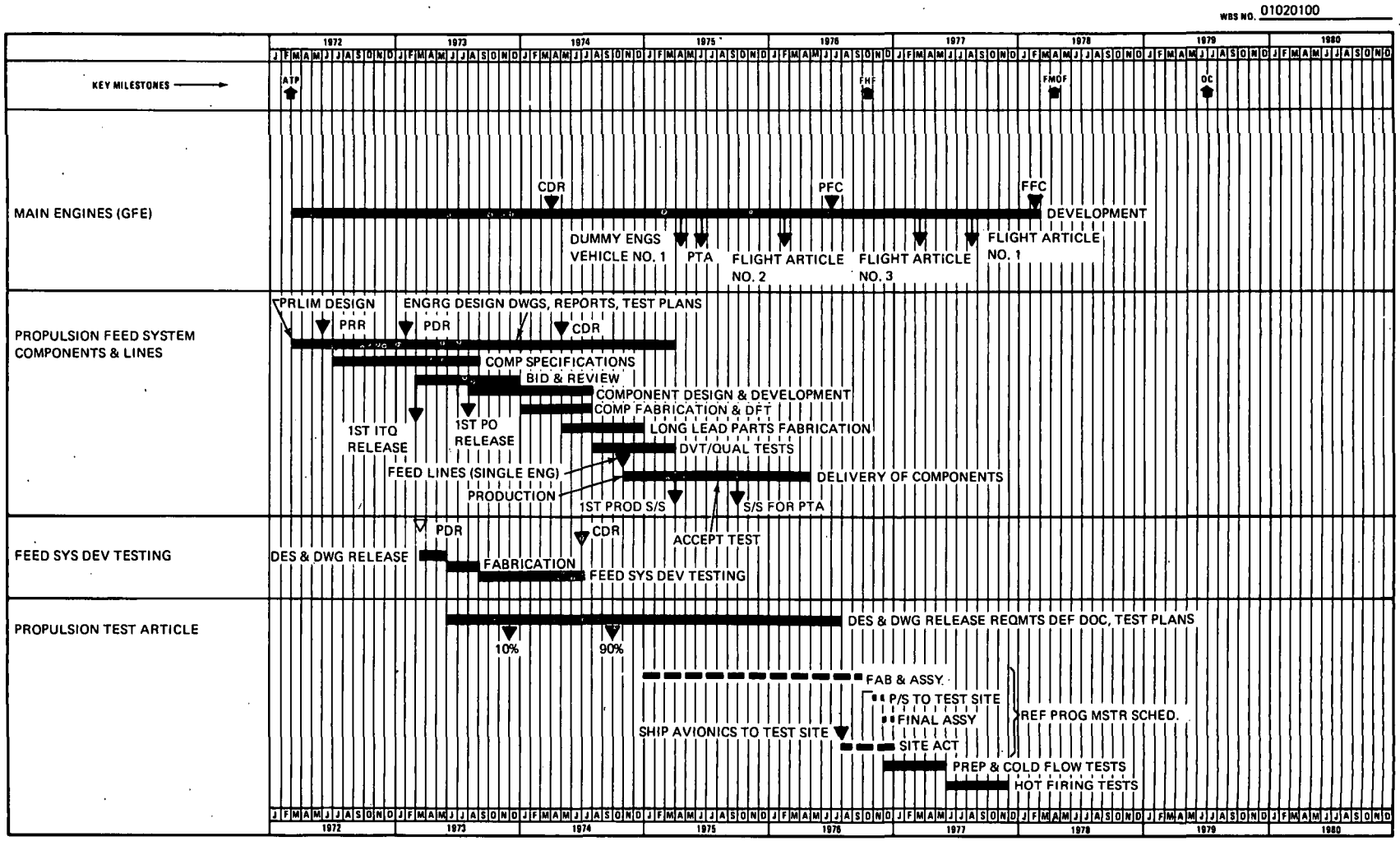


Fig. 4.1-3 Main Propulsion System Schedule

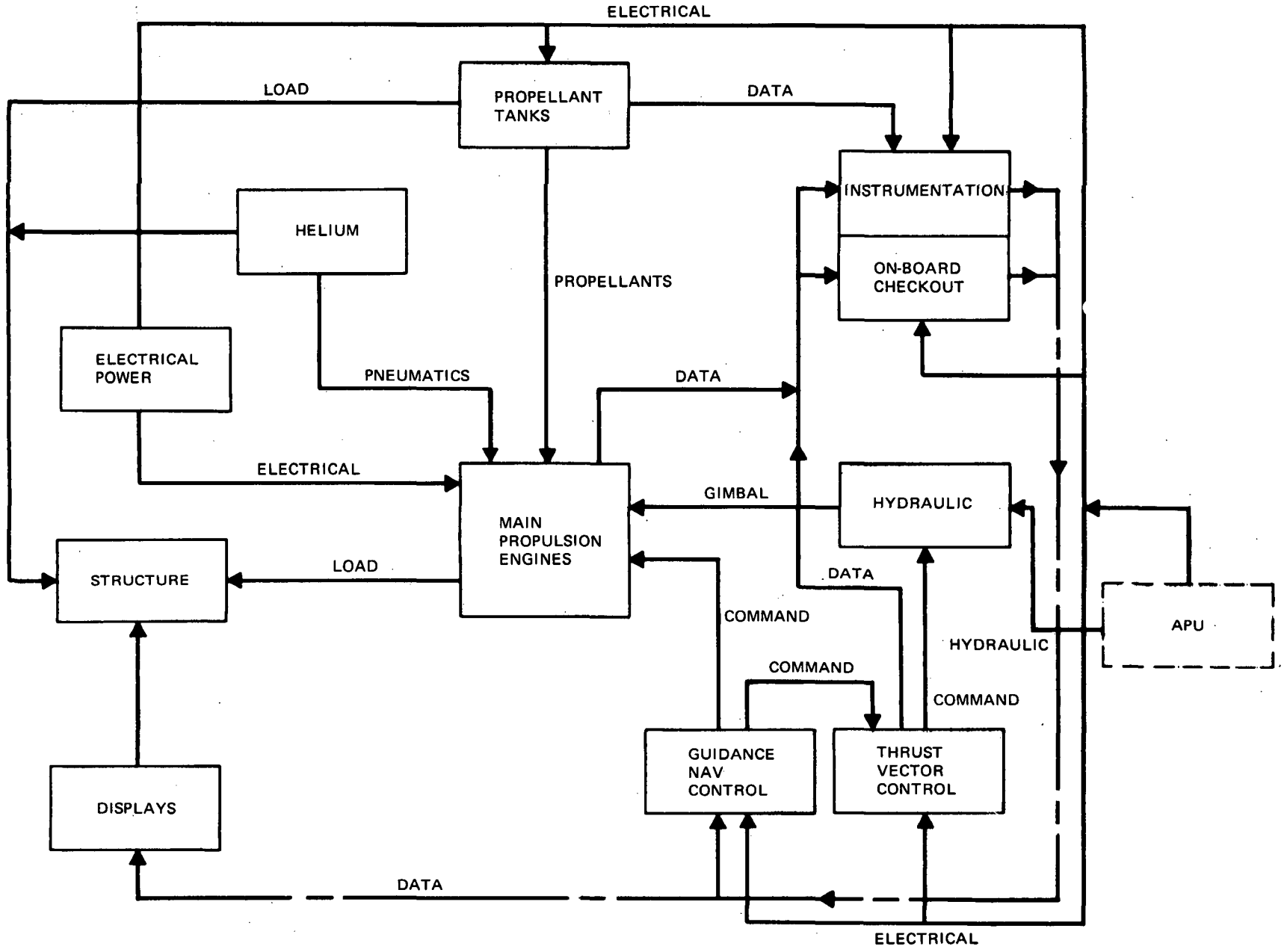


Fig. 4.1-4 Main Propulsion Functional Block Diagram

TABLE 4.1-1 MAIN PROPULSION SUBSYSTEM
CERTIFICATION REQUIREMENTS (Sheet 1 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | PTA | Flight Vehicle |
| Disconnect - $LH_2$ Fill | | | X | | X | | X | | | |
| Disconnect - $LO_2$ Fill | | | X | | X | | X | | | |
| Fill Valve - $LH_2$ | | | X | | X | | X | | | |
| Fill Valve - $LO_2$ | | | X | | X | | X | | | |
| Interconnect Valve - $LH_2$ OMS | | | | | | X | X | | | |
| Interconnect Valve - $LO_2$ OMS | | | | | | X | X | | | |
| Prevalve - $LH_2$ | | | X | X | | X | X | | | |
| Prevalve - $LO_2$ | | | X | X | | X | X | | | |
| Check Valve - $LH_2$ Series | | | X | X | | X | X | | | |
| Check Valve - $LO_2$ Series | | | X | X | | X | X | | | |
| Shutoff Valve - $O_2$ | | | X | | | X | X | | | |
| Vent - $O_2$ Zero Thrust | | | X | | X | | | | | X |
| Vent - $H_2$ Zero Thrust | | | X | | X | | | | | X |
| Relief Valve - $O_2$ Series - High Press | | | X | | | X | X | | | |
| Relief Valve - $H_2$ Series - High Press | | | X | | | X | X | | | |
| Vent Valve - $O_2$ Ground | | | X | | | X | X | | | |
| Disconnect - $O_2$ Gnd. Pressure | | | X | X | X | | X | | | |
| Pressurization Valve - $H_2$ Gnd. Vent | | | X | | | X | X | | | |
| Disconnect - $H_2$ Gnd. Vent & Press | | | X | X | X | | X | | | |
| Disconnect - $LH_2$ Drop Tank - Feed | | | | | | X | X | | | |
| Disconnect - $LH_2$ Drop Tank - Circ. | | | | | | X | X | | | |

TABLE 4.1-1 MAIN PROPULSION SUBSYSTEM
CERTIFICATION REQUIREMENTS (Sheet 2 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | PTA | Flight Vehicle |
| Check Valve - $O_2$ Flapper | | | X | | X | | X | | | |
| Disconnect - $H_2$ Drop Tank - Press/Vent | | | | | | X | X | | | |
| Level Sensor - $O_2$ Loading | | | X | X | X | | X | | | |
| Level Sensor - $H_2$ Loading | | | X | X | X | | X | | | |
| Level Sensor - $H_2$ Low Level | | | X | X | | X | X | | | |
| Level Sensor - $O_2$ Low Level | | | X | X | | X | X | | | |
| Ball Joints - $H_2$ | | | X | X | X | | | X | | |
| Ball Joints - $O_2$ | | | X | X | X | | | X | | |
| Pressure/Volume Compensators | | | X | X | X | | | X | | |
| Tank $LH_2$ | | | | | | X | | X | | |
| Tank $LO_2$ | | | | | | X | | X | | |
| Operational Requirements | | | | | | | | | | |
| • Demonstrate propellant flow/management | X | X | | | | | | | X | |
| • Demonstrate engine inlet feed system requirement | X | X | | | | | | | X | |
| • Demonstrate engine system start/stop transients | | | | | X | | | | X | |
| • Verify propellant conditions at engine inlet | X | | | | X | | | | X | |
| • Verify performance of TVC when coupled to APU hydraulics | | X | | | X | | | | | X |

TABLE 4.1-1 MAIN PROPULSION SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 3 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | PTA | Flight Vehicle |
| • Evaluate engine/thrust mt/structural compatibility | | | | | X | | | | X | X |
| • Demonstrate mission duty cycle requirement | X | | | | X | | X | | | X |
| • Demonstrate malfunction/failure requirement | X | | | | X | | | | X | |
| • Demonstrate propellant dump capability | | | | | X | | | | | X |
| • Demonstrate $LH_2$ tank separation sequence | | X | | | X | | | X | | |
| Interface Requirements | | | | | | | | | | |
| • Demonstrate propellant loading control | X | | | | X | | | | X | |
| • Verify propellant loading rates | X | | | | X | | | | X | |
| • Demonstrate effectiveness of tank and line thermal protection | | | | | X | | | | X | |
| • Verify operation of engine conditioning and recirculation system | X | | | | X | | | | X | |
| • Demonstrate accessibility, replacement, and verification of system integrity | | | | | X | | | | X | |
| • Demonstrate the checkout, performance monitoring, data management, and sensor capability of the MPS/OCMS (onboard checkout and monitor systems) | | | | | X | | | | X | |
| • Demonstrate autogenous pressurization control | | | | | X | | | | X | |

TABLE 4.1-1 MAIN PROPULSION SUBSYSTEM
CERTIFICATION REQUIREMENTS (Sheet 4 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | PTA | Flight Vehicle |
| • Ability to start-up MPS in the pre-separation boost environment | X | X | | | X | | | | | X |
| • Verify post-flight status of MPS hardware for ability to reuse on next flight mission | X | | | | X | | | | | X |

TABLE 4.1-2 REQUIRED EQUIVALENT UNITS
MAIN PROPULSION SUBSYSTEM

| Hardware Description | Required Equivalent Units |
|---|---|
| Flight Hardware per Vehicle | 1 |
| Component Devel & Qual Test | 2 |
| Integration Tests | |
| • Full mission simulation lab | |
| • Integrated avionics test lab | |
| • Flight controls hydraulic test lab | |
| • Mechanical systems test rigs | |
| • Propulsion fluid breadboards | |
| • Escape system test rig | |
| Test Articles | |
| • Propulsion test article | 1.5 |
| • Structural test article | |
| Spares for Flight Test Program | 1.5 |
| Spares for 445 Flights | 2 |

TABLE 4.1-3 BOOSTER/ORBITER COMMONALITY STUDY
(Sheet 1 of 3)

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Design Philosophy | | | | |
| • Shall be designed for FO/FS | X | | | ASSC Study Control Document, Sept 19 |
| • Single main engine out on the B shall permit nominal mission continuation; on the O: a safe abort capability | | | X | ASSC Study Control Document, Sept 19 |
| • There shall be no propellant crossfeed between stages | X | | | ASSC Study Control Document, Sept 19 |
| • Propulsion systems shall be capable of safe shutdown at any time | X | | | ASSC Study Control Document, Sept 19 |
| • Requirements for He shall be minimized | X | | | ASSC Study Control Document, Sept 19 |
| • Capability to jettison or deplete propellants prior to landing shall be provided | X | | | ASSC Study Control Document, Sept 19 |
| • Service lines at the launch pad shall be provided for the main propulsion propellants | X | | | ASSC Study Control Document, Sept 19 |
| • Flight performance reserve requirement with a closed loop utilization system is 1% of total propulsive velocity and 1.0% without a propellant utilization system if fuel is biased | X | | | |

TABLE 4.1-3 BOOSTER/ORBITER COMMONALITY STUDY
(Sheet 2 of 3)

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Equipment | | | | |
| • Main engine power head | X | | | Per engine ICD, 13M15000 |
| • Engine nozzles | | | X | Orbiter $\epsilon$ = 150; Booster $\epsilon$ = 35 |
| • Various valves and lines | | X | | |
| $LH_2$ & $LO_2$ Delivery System | | | | See TBC coordination sheet 2-2920-0000-133 dated 2/8/71 |
| • Storage tank - $LH_2$ | | | (H) X | B uses internal tank with internal insulation; O uses external tanks (2) with external insulation |
| • Delivery manifold system | X | | X | B has 2 delivery manifolds that feed six engines each; O has 2 delivery manifolds feeding 3 engines. However, pre-valves are common |
| • Fill and drain system | | X | | B & O fill is a 3-phase operation |
| • Pressurization system | | X | | B & O uses $GH_2$ |
| • Pre-pressurization | | X | | B & O uses GHe |
| • System pressure - $LH_2$ | | | X | B at 19.3 psi; O at 25-27 psi |
| • $LH_2$ vent system | | X | | B vents to GSE on ground and to APU in flight O vents to GSE on ground and to vacuum in flight |
| • $LH_2$ lines | | X | | B & O use vacuum jacketed lines |



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TABLE 4.1-3 BOOSTER/ORBITER COMMONALITY STUDY
(Sheet 3 of 3)

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| • Uninsulated storage tank - $LO_2$ | | | X | B uses integral tank, O uses non-integral tanks (2) |
| • System pressure - $LO_2$ | | X | | B at 32 psi; O at 25-27 psi |
| • $LO_2$ vent system | | X | | B & O vent overboard on the pad and through a relief valve overboard in flight |
| • Main engine purge | | X | | B & O use $GN_2$ for ground purging and GHe in flight |

TABLE 4.1-4 MPS (SUBASSEMBLY FLOW TEST)
SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Test fixture (for mounting propellant lines)<br>• Engine flow simulator, with remote-op valving and replaceable flow control orifices (3 required)<br>• Tank pressurization system and control console<br>• Low level sensors, incl read-out<br>• Propellant fill and drain system and control console<br>• Instrumentation and recording system<br>• Helium pneumatic supply system (for purging and valve actuation)<br>• Gas leak detection equipment |
| Software | • Component data reduction program<br>• Flow control sequencing program<br>• Cold flow data reduction program |

TABLE 4.1-5 MPS (SUBASSEMBLY FLOW TEST)
FACILITY REQUIREMENTS

| Title and Description | New | Exist. | Contr | Govt |
|---|---|---|---|---|
| • $LO_2$ & $LH_2$ Storage Tanks* | | X | | X |
| • $LO_2$ & $LH_2$ Run Tanks* | | X | | X |

*Assumed to be available at MTF or MSFC. Alternate to either could be propellant line vendor's test facility (or his Test Lab subcontractor).

TABLE 4.1-6 SHUTTLE PHASE C/D BUDGETARY ENGINEERING ESTIMATE COMPUTING REQUIREMENTS INPUT FORM

| | | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Keypunch, Hrs/Yr | | 160 | 280 | 240 | 240 | 200 | 160 | 100 | 120 | 120 | 40 | 20 | 20 | 20 | 20 | 20 | 20 | 1780 |
| Machine Time Estimate, Hrs/Yr | 360-75 | 80 | 140 | 120 | 120 | 100 | 80 | 50 | 60 | 60 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 890 |
| | 360-67 | 8 | 14 | 12 | 12 | 10 | 8 | 5 | 6 | 6 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 89 |
| | 360-30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | _____ | | | | | | | | | | | | | | | | | |
| | _____ | | | | | | | | | | | | | | | | | |
| | _____ | | | | | | | | | | | | | | | | | |
| | _____ | | | | | | | | | | | | | | | | | |
| Programming Estimate, Man-Months | | 12 | 12 | 12 | 12 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |

## 4.2 AIR BREATHING PROPULSION SUBSYSTEM (ABPS)

### 4.2.1 SUBSYSTEM DESCRIPTION

The baseline common booster/orbiter engine is a non-afterburning space-proofed version of the low bypass ratio Pratt and Whitney turbofan JTF22A engine developed for the F-14B airplane.

Four deployable pod-mounted engines are used. They are stored in non-pressurized compartments during the space mission, deployed at 35,000 ft, and started by windmilling with starter assist; pressurized gaseous hydrogen from the ACPS accumulator is used to energize the pneumatic starter. A block diagram of the ABPS is shown in Fig. 4.2-1.

The ABPS provides the following:

- Thrust availability during post reentry descent and landing, with enough fuel for one go-around
- Thrust to fly the orbiter as a conventional airplane for horizontal flight tests, and for ferry duty. An additional engine and a ferry fuel tank are required to provide sufficient flight duration

Fuel is stored in a single pressurized and thermally protected tank which includes dual booster pumps. Each engine is fed through an individual isolation valve ahead of the deployable swivel section. The isolation valves are closed and the lines drained prior to launch. Vents are provided at the engines to insure rapid filling of the lines after deployment. Standard hydraulically controlled pressure fueling devices are used to fuel and defuel the mission tank in the horizontal and vertical positions. The fuel system is shown in Fig. 4.2-2.

Lube oil is stored in an isolation tank and the engine bearings flushed prior to launch to eliminate harmful out gassing effects.

The baseline mission configuration includes interfaces for the installation of ferry equipment.

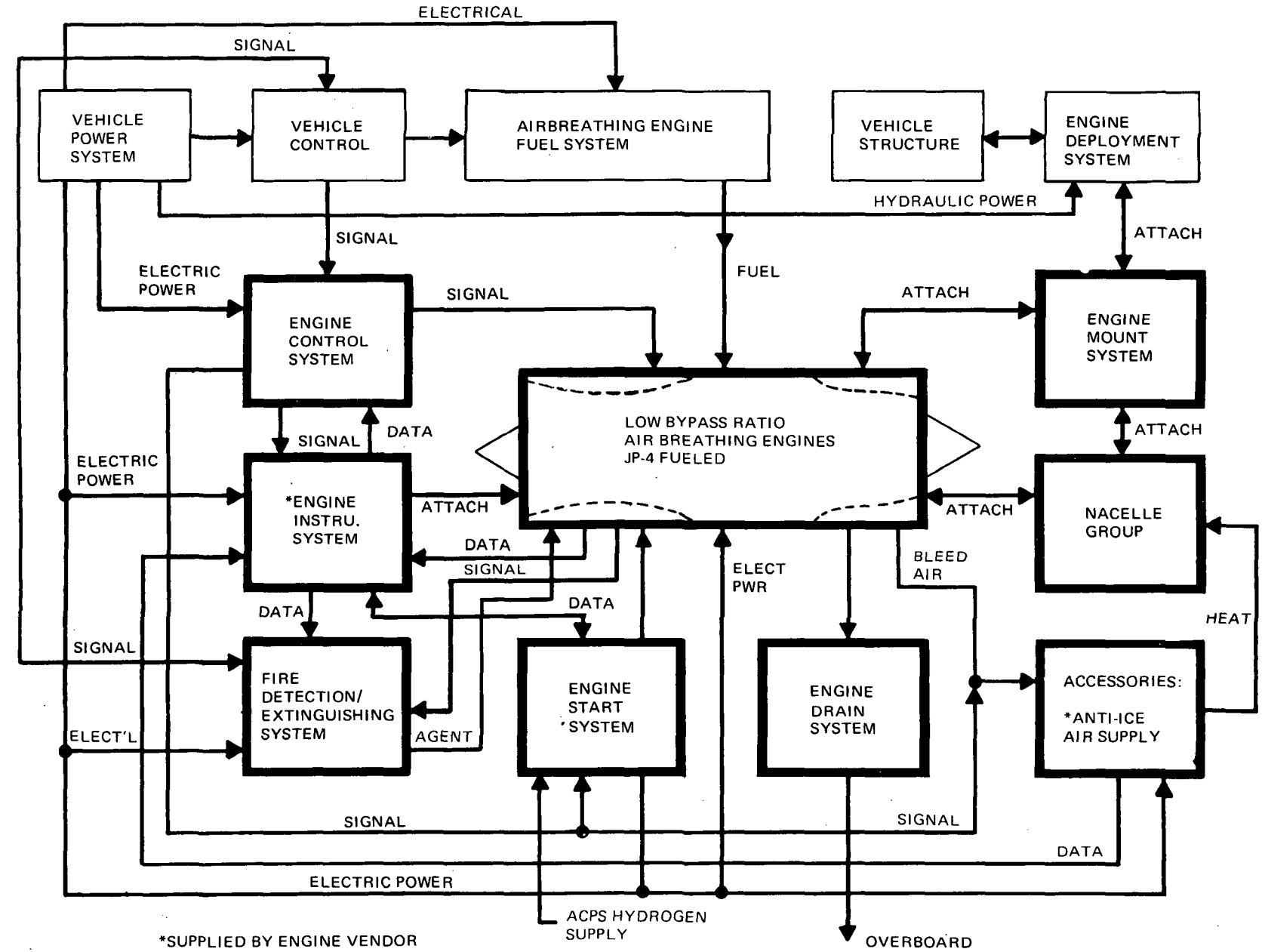


Fig. 4.2-1 Air Breathing Propulsion Subsystem

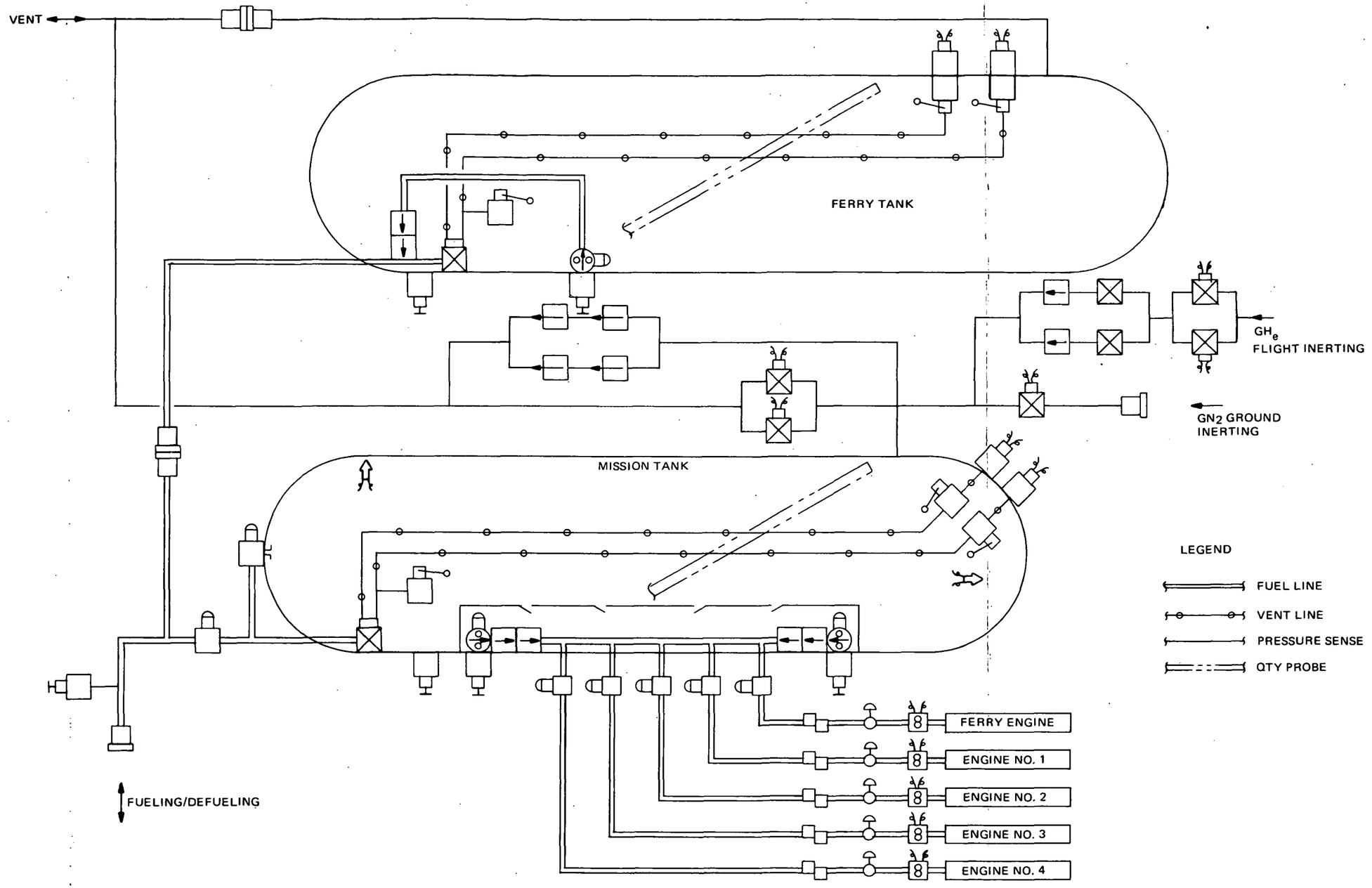


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Fig. 4.2-2 Orbiter Air Breathing Propulsion/ JP Fuel Subsystem

## 4.2.2 E&D PLAN RATIONALE

The objective of the E&D effort is to verify the innovations required to resolve technical issues and to qualify the subsystem components. The integrated ABPS will be finally certified during the flight test program.

The air breathing propulsion subsystem (ABPS) uses, except for the innovations discussed hereafter, design concepts, component/assembly hardware, and operating modes presently used in conventional subsonic aircraft. As a result, the component procurement-to-delivery cycle will be relatively short and DVT/qualification testing will be only that required for special components and shuttle environmental needs. Ancillary subsystems such as fire protection, anti-icing, and air bleed may be procured as subcontractor items with no major changes from off-the-shelf hardware. Engine inlets and exhaust nozzle designs, based on in-house experience and supported by wind tunnel model tests, will be verified on the flight vehicle.

The major technical issues specific to the shuttle requirements are:

- Space proofing of the ABPS
- Axial (vertical) launch environment loads on dry bearings
- Short duration windmilling on dry bearings
- Starting of the engines in flight
- Deployable mechanisms integrity (including fluid lines)
- Fueling and inerting of the fuel tank in horizontal and vertical attitudes
- Use of hydrogen in a pneumatic starter

These issues are common to the booster and orbiter with the exception of space proofing and the hydrogen starter.

## 4.2.3 DESIGN VERIFICATION TESTS (DVT)

Spaceproofing of the engine will be verified by vacuum tests of affected engine components and of the engine assembly. The technical issue is the retention of properties and performance after the cyclic environmental changes of the shuttle. This needs verification early in the program. The pre-launch procedure includes isolation of the lube oil tank,

flushing of the bearings with a volatile solvent, and draining of all fluids. The ability of dry bearings to withstand launch environment loads and windmilling loads until the lube oil feed system is reactivated must be verified to validate the procedure. Complete engine(s) vacuum tests under representative mission thermal profiles will be conducted in order to verify spaceproofing and lube activation provisions at the engine level. The engine will also be subjected to launch environment load tests in pre-launch condition and attitude (vertical).

Engine performance and durability will be verified by conventional PFRT and FRT. Major components of the fuel system affected by the environment will be subjected to vacuum/thermal tests as required.

Thermal control of the engine compartment and mission fuel tank is important during the cryo-fueling and entire pre-launch period due to the large masses of cryogenics surrounding the ABPS and during reentry and cross range because of the high temperature encountered at that time. These thermal problems are amenable to theoretical analysis and will be so treated. The engine is designed for -65 to +250°F soak capability (the latter for 15 minutes), and thermal control of the engine storage compartment will be necessary. The fuel tank will be provided with an insulation blanket readily replaceable with an active electric blanket, if found necessary, to keep the fuel within the limits of -58 to +135°F. Fuel lines which are emptied prior to launch will not need protection. Conditioning of the engine storage compartment during the pre-launch period will be made a part of ground procedures, if found necessary.

The engine deployment system will be verified on the structural article (subsection 10.2). These tests will demonstrate structural stability of the engine platform and engine mounts in both stored and deployed positions and will verify the integrity of storage and deployment features; in particular, the door seal, the hydraulic actuators, the deployable fuel and starter lines under simulated dynamic and thermal conditions. Further verification of pre-launch procedures, deployment, and lube system activation will be made by ground tests on the horizontal flight test article.

Adaptation of a pneumatic starter to air/hydrogen capability will be verified by tests. Predicted performance of the air turbine using hydrogen at the ACPS accumulator temperature of 250 to 500°R will be verified by bench testing and, if necessary, a compromise design favoring hydrogen will be incorporated since ground start duration is of secondary importance. The existing starter air pressure regulator will be either adapted or supplemented with a hydrogen regulator. Modification of the starter to make the casing and exhaust collector hydrogen-tight will be bench-tested to verify sealing integrity. Articulated hydrogen line joints will be evaluated for this application wherein deployment is effected prior to utilization. Isolation valves will be certified for space application.

Engine air-start, already documented with F-14B data, will be verified during horizontal test flights. Although the horizontal flights will be at a lesser altitude than the baseline mission, the system capability to start at or above the minimum safe altitude of 10,000 ft will be verified prior to vertical flights.

The ferry configuration must be used for horizontal flight to allow sufficient flight time and, consequently, the ferry kit capability will be verified during this phase of the program.

A relatively modest fuel system test program will be conducted to verify specific shuttle provisions, such as the deployable fuel lines, the two-attitude horizontal/vertical fueling system, and the ferry-tank to mission-tank transfer network.

A PFRT configured engine assembly will be tested with a bell mouth inlet on the Grumman Peconic sea level test stand. This will provide verification of the operation of engine components such as controls, starter and instrumentation, and, if required, measurement of engine performance in support of the flight test program.

### 4.2.2 COMPUTER SUPPORT REQUIREMENTS

Computer programming will be required to design, develop, and evaluate the performance of components and subassemblies of the air breathing engine subsystem.

- Installed performance program (IPP) - to evaluate the effect of component efficiencies on thrust and fuel flow of the engine

- Propulsion evaluation program (PEP) - to optimize inlet and exhaust nozzle designs and other auxiliary flow systems
- Piping program (ALICAT) - to optimize line runs
- Fuel flow characteristics program - to determine pressure drops and fuel management
- Computergraphic program - to establish engine installation envelopes
- Engine starting program - to evaluate engine starting dynamics during start

All of the programs are now operational on the 360/75 computer. Requirements for the duration of the program are as follows:

| GDS Service | Year | | |
|---|---|---|---|
| | 1972 - 1975 | 1976 - 1980 | 1981 - 1987 |
| Machine time, hr/mo | 1 | 1/2 | 1/4 |
| Card Punch, hr/mo | 2 | 1 | 1/2 |

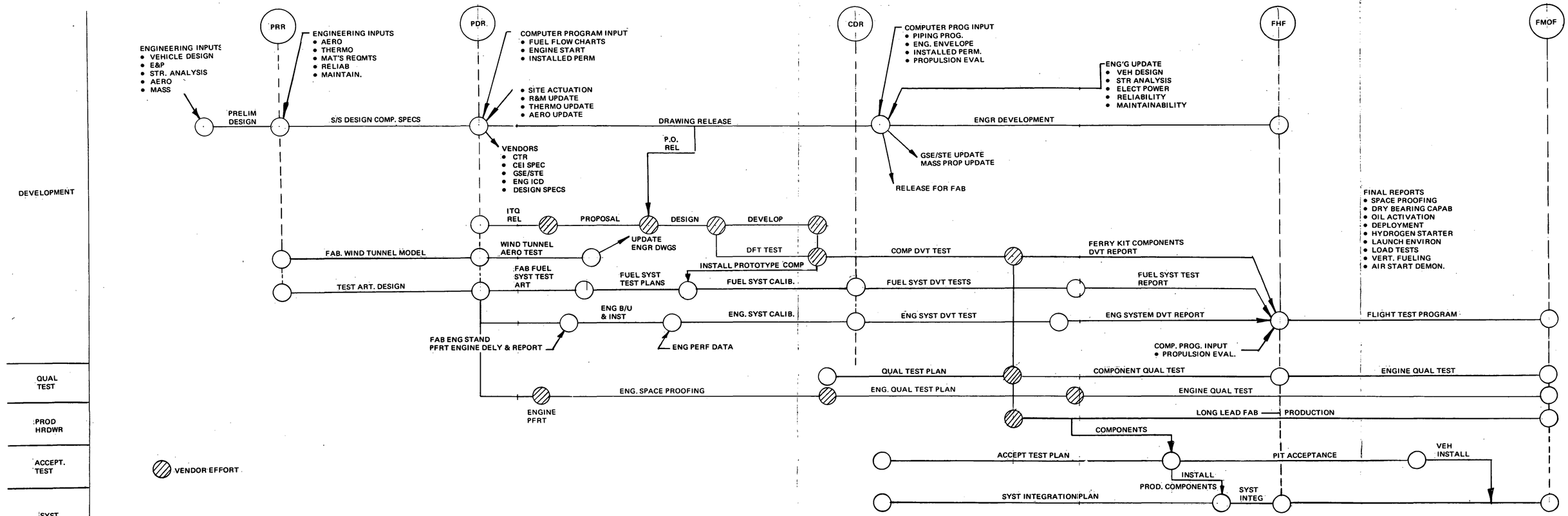


Fig. 4.2-3 Air Breathing Propulsion Logic Network



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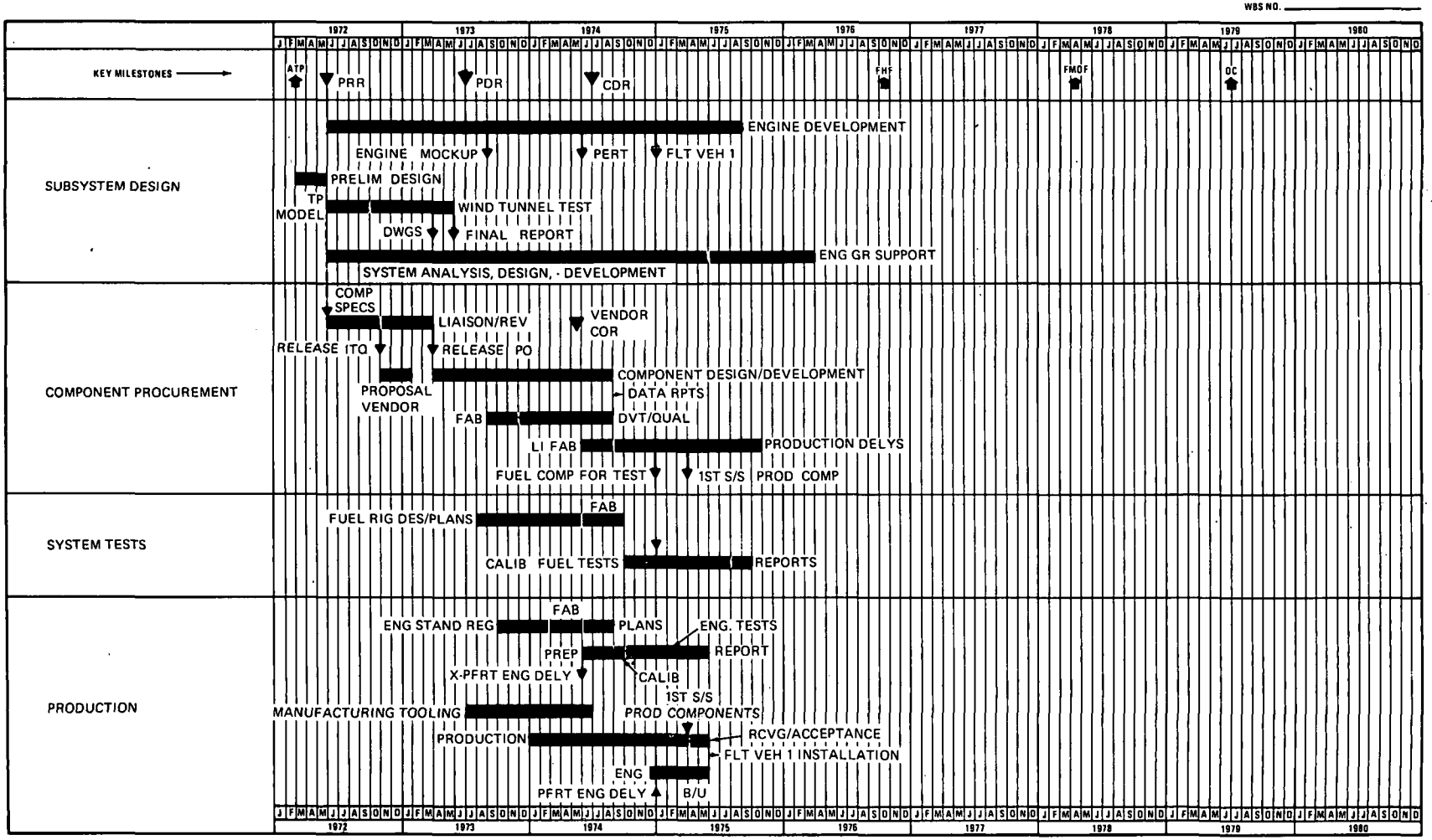




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Fig. 4.2-4 Propulsion/Air Breathing Engine System

TABLE 4.2-1 AIR BREATHING ENGINE SUBSYSTEM
CERTIFICATION REQUIREMENTS (Sheet 1 of 3)

| Certification Requirement | Certification Method | | | | | | | Level of Assembly | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Engines - turbofan | | | | | X | X | X | | | | |
| Engine mounts | | | | | | X | X | | | | |
| Actuators for deployment | | | X | | X | | X | | | | |
| Starter - engine | | | X | | X | | X | | | | |
| $GH_2$ flexible connector - starter | | | X | | X | X | X | | | | |
| $GH_2$ isolation valve | | | X | | X | | X | | | | |
| Shut-off valve - bleed air | | | X | | | | X | | | | |
| Check valve - bleed air | | | X | | | | X | | | | |
| Fire detection system | | | X | | X | | | X | | | |
| Fire extinguishing system | | | X | | X | | | X | | | |
| Fuel tank - orbital mission | | | | | X | X | X | | | | |
| Fuel tank - horizontal flight test & ferry | | | | | X | X | X | | | | |
| Boost pumps - fuel | | | X | | X | | X | | | | |
| Shut-off valve - engine | | | X | | X | | X | | | | |
| Shut-off valve - refueling | | | X | | X | | X | | | | |
| Cross feed valve | | | X | | X | | X | | | | |
| Shut-off valve - vent | | | X | | | | X | | | | |
| Shut-off valve -pressurization | | | X | | X | | X | | | | |
| Regulator - fuel pressurization | | | X | | X | | X | | | | |

TABLE 4.2-1 AIR BREATHING ENGINE SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 2 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Relief valve - pressurization | | | X | | | | X | | | | |
| Flowmeter - fuel | | | X | | X | | X | | | | |
| Directional valve - pressurization | | | X | | X | | X | | | | |
| Level control valve | | | X | | X | | X | | | | |
| Gaging system - orbital mission tank | | | X | | X | X | X | | | | |
| Gaging system - horizontal flight test tank | | | X | | X | | X | | | | |
| Disconnect/adapter - fill | | | X | X | | | X | | | | |
| Disconnect - vent | | | X | X | | | X | | | | |
| Check valve - fuel feed | | | X | | X | | X | | | | |
| Interface Requirements | | | | | | | | | | | |
| • Demonstrate fuel loading accuracy | X | | | | X | | | X | | | |
| • Demonstrate fuel inlet feed conditions to each engine | X | | | | X | | | X | | | |
| • Verify air start capability for each engine | | | | | X | | | | | | X |
| • Demonstrate fuel system integrity | | | | | | | | | | | X |
| • Demonstrate fire detection system operational capability - short detection | | | | | | | | | | | X |

TABLE 4.2-1 AIR BREATHING ENGINE SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 3 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analysis | Simulation | Similarity | Common Usage | Test DVT | Test Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Demonstrate fire extinguishing system operational capability for single engine $CF_3B_R$ inerting | | | | | | | | | | | X |
| • Demonstrate adequate fuel capacity for landing go-around mission | X | | | | | | | X | | | |
| • Demonstrate adequate fuel capacity for ferry mission | X | | | | | | | X | | | |
| Operational Requirements | | | | | | | | | | | |
| • Demonstrate engine operation max. power | | | | | | | | | | | X |
| • Demonstrate engine air/start capability | | | | | | | | | | | X |
| • Demonstrate engine/structure integrity and vibration cond | | | | | | | | | | | X |
| • Demonstrate system purging capability | | | | | | | | | | | X |
| • Demonstrate engine deployment | | | | | | | | X | | | |

TABLE 4.2-2 ABPS MAJOR SUBASSEMBLIES

| Subassembly Description | Qty/ Vehicle | Weight, Lb | Size Each | Total Weight |
|---|---|---|---|---|
| • Engine buildup assembly including lube oil, engine anti-icing, controls, and harnesses instrumentation | 4 | 2500 | | 10,000 |
| • Engine nacelle group including engine mounts, pylons, inlet with anti-icing provisions, cowling, exhaust nozzle and fluid drains | 4 | 510 | | 2040 |
| • Starting system including pneumatic starter, hydrogen feed lines, and isolation valves | 4 | 65 | | 240 |
| • Mission fuel storage system including tank, booster pumps, quantity gages, valves, lines, flow meter interfaces, and attachments | 1 | 400 | 67 cu ft | 400 |
| • Deployable engine support (clamshell) including hinges, actuators, latches, recycling doors, and deployable lines | 2 | 910 | | 1820 |
| | | | | 14,500 |
| • Contingencies | | | | 510 |
| • ABPS mission configuration | | | | 15,010 |
| • Ferry tank | 1 | 1500 | 925 cu ft | |
| • Ferry podded engine assembly | 1 | 3010 | | |

TABLE 4.2-3 REQUIRED EQUIVALENT UNITS

AIR BREATHING ENGINE SUBSYSTEM *

| Hardware Description | Required Equiv. Units |
|---|---|
| Flight hardware per vehicle | 1 |
| Component devel & qual test | 1.5 |
| Integration tests | |
| • Full mission simulation lab | |
| • Integrated avionics test lab | |
| • Flight controls hydraulic test lab | |
| • Mechanical systems test rigs | |
| • Propulsion fluid breadboards | 1.25 |
| • Escape system test rig | |
| Test articles | |
| • Propulsion test article | |
| • Structural test article | |
| Spares for flight test program | 1 |
| Spares for 445 flights | 2 |

*Engines assumed GFE. For CFE equivalent units of engines and components used by engine manufacturer in his development program must be included.

TABLE 4.2-4 AIR BREATHING ENGINE SUBSYSTEM BOOSTER/ ORBITER COMMONALITY CANDIDATES LIST (Sheet 1 of 2)

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Engine | X | | | |
| Lubrication system | X | | | |
| Starting system | | X | | |
| Anti-icing system | | X | | |
| Fire detection | | X | | |
| Fire extinguishing | | X | | |
| Engine drain system | | X | | |
| Bleed air system (ferry) | | | X | |
| Nacelle group | | | X | |
| Engine mounts | | | X | |
| Deployment mechanism | | | X | |
| Fuel pumps | | X | | |
| Fuel line valves | | X | | |
| Fuel tanks | | | X | |
| Tank pressurization | | X | | |
| Fuel vent system | | | X | |
| Tank thermal protection | | | X | |
| Fuel gaging | | | X | |
| Onboard check-out | | X | | |



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TABLE 4.2-4 AIR BREATHING ENGINE SUBSYSTEM BOOSTER/
ORBITER COMMONALITY CANDIDATES LIST (Sheet 2 of 2)

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Displays | | X | | |
| Control actuation units | | X | | |
| Ground start | | X | | |
| Facility | | X | | |
| Support equipment | | X | | |
| Software | | X | | |

TABLE 4.2-5 AIR BREATHING ENGINE
SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | JP-4 Storage/Transfer Equipment<br>$GN_2$ Storage/Transfer Equipment<br>He Storage/Transfer Equipment<br>Ground start cart<br>Test Control Console<br>Control/simulation/data acquisition computing capability<br>Hydraulic servicing unit<br>Hydraulic power unit<br>Thrust measuring system<br>Thrust Deflectors & Sound Absorbers<br>Engine tool kit<br>Structure to support test article |
| Software | Programs for:<br>- Test sequence control<br>- Data acquisition<br>- TV display of test data<br>- Data Analysis<br>- Test Reporting |
| | |

TABLE 4.2-6 AIR BREATHING ENGINE SUBSYSTEM

FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Govt |
|---|---|---|---|---|
| • Engineering floor space | | X | | |
| • Mock-up rooms | | X | | |
| - Deployment mechanism | | | | |
| - Engine mock-up | | | | |
| • Wind tunnels | | | | |
| - Low speed tunnel | | X | GAC | |
| - Transonic tunnel | | X | GAC | |
| - LRC 8 ft transonic | | X | | X |
| - LRC 16 ft transonic | | X | | X |
| - Other facilities (sub & transonic) as required (Testing is piggy-back with aerodynamics) | | | | |
| • Test facilities | | | | |
| - Fuel lab | | X | GAC | |
| - Fuel flow bench facility | | X | GAC | |
| - Hydraulic bench facility | | X | GAC | |
| - Engine test stand | | | | |

# 4.3 ORBIT MANEUVERING SYSTEM (OMS)

## 4.3.1 DISCUSSION

The orbit maneuvering system provides major velocity changes after orbital insertion, de-orbit velocity impulse at mission end, and backup velocity impulse for abort-to-orbit when required. Fig. 4.3-1 is a functional schematic of the OMS. Fig. 4.3-2 and Table 4.3-2 show a fluid schematic and a list of the OMS components.

The certification of the OMS will commence with development testing of individual components, progress to testing of assemblies to verify operation, and culminate with subsystem certification and off-nominal testing using an integrated OMS test rig. Since the OMS and ACPS are independent except for common propellant tanks, the OMS certification program will not be constrained by the ACPS development. Therefore OMS/ACPS integrated testing is not required, reducing test complexity.

The OMS engines and each individual fluid component of the feed, vent, pressurization, and ambient helium sections will undergo extensive development testing prior to the integrated test sequence which will be used to certify operation of the OMS. In particular, although the RL10 engine has a long, successful history in the space program, the model chosen for the OMS will undergo extensive development for the shuttle program. For example, the supplier will verify critical items such as extended lifetime, dual ignition, idle mode operation, and cold gas autogenous tap-off prior to the start of integrated testing. By using qualifiable components on the integrated test rig, the planned OMS certification program will be assured of meeting all of its objectives in a cost-effective manner.

Prior to the start of the integrated tests, the propellant feed system and cryogenic helium system will be thoroughly tested as assemblies. These assemblies will use qualifiable hardware and are used so that (1) feed system problems may be screened out and corrected so as not to constrain integrated testing; and (2) the cryogenic helium need

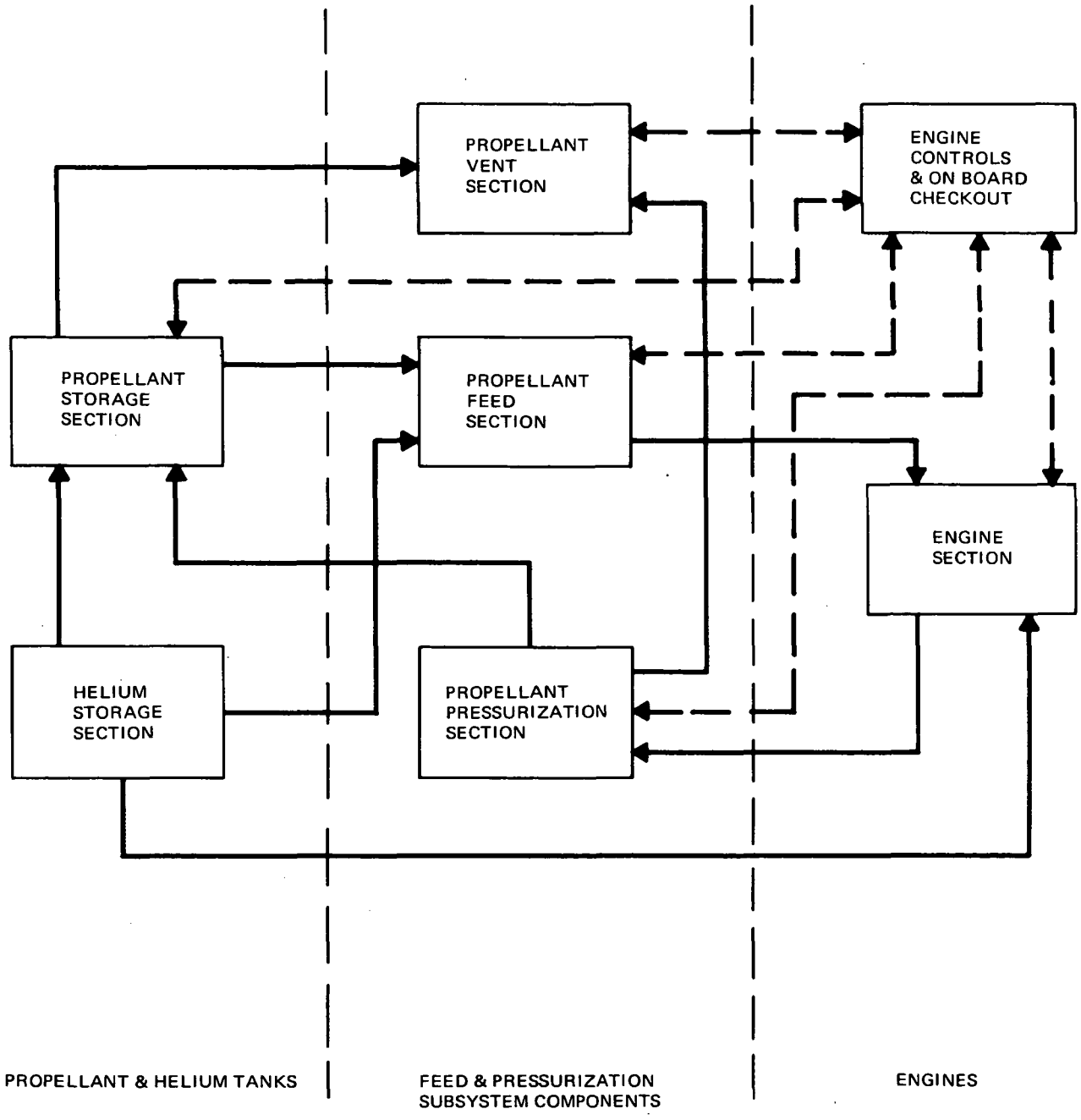
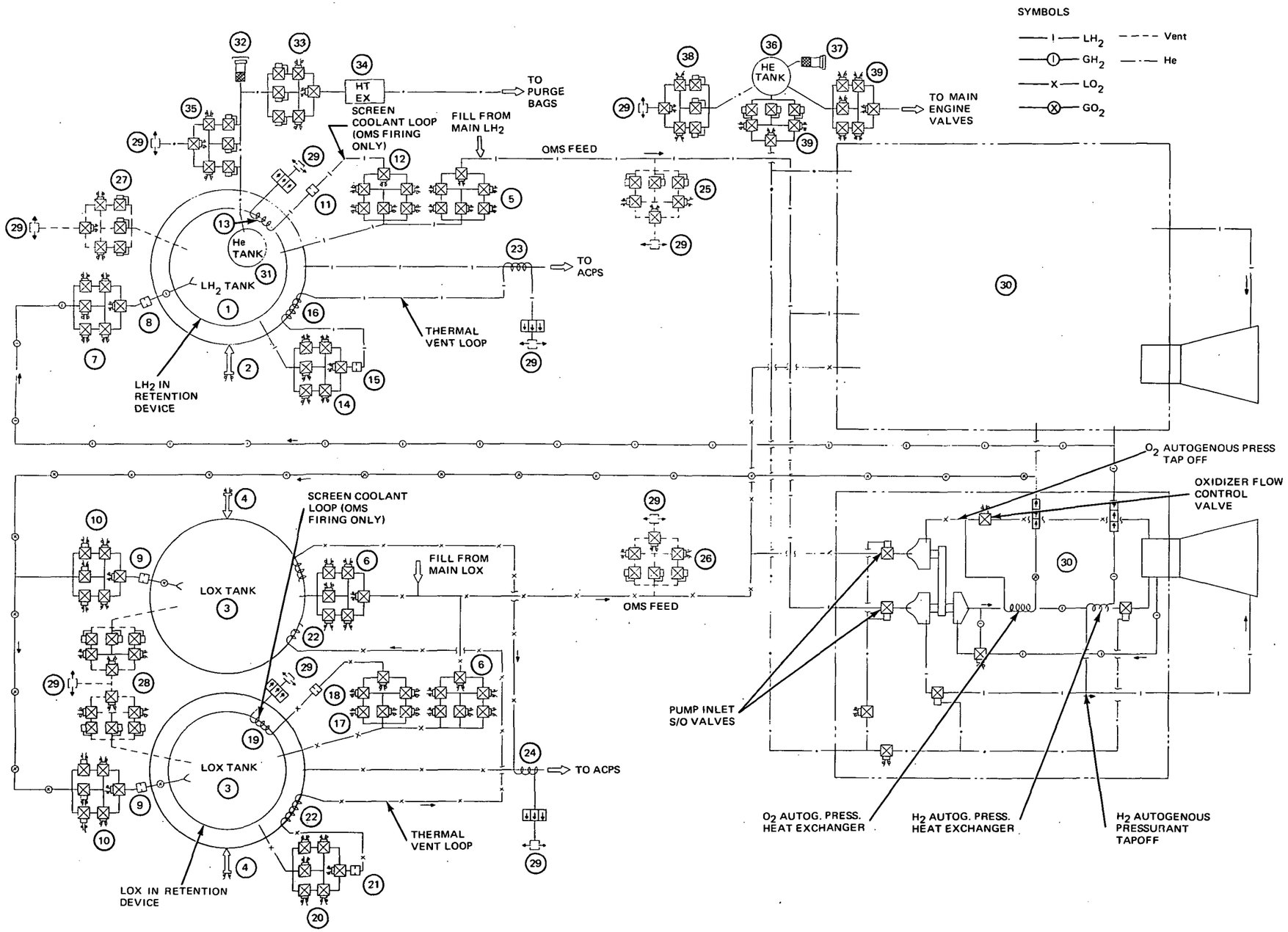



Fig. 4.3-1 OMS Functional Logic

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COMPONENT IDENTIFICATION

| Item | Description |
|---|---|
| 1 | $LH_2$ TANK |
| 2 | $LH_2$ TANK CAPACITANCE PROBE |
| 3 | LOX TANK |
| 4 | LOX TANK CAPACITANCE PROBE |
| 5 | $LH_2$ TANK SHUT OFF VALVE PACKAGE |
| 6 | LOX TANK SHUT OFF VALVE PACKAGE |
| 7 | $H_2$ AUTOGENOUS PRESSURIZATION SHUT OFF VALVE PACKAGE |
| 8 | $H_2$ AUTOGENOUS PRESSURANT EXPANDER |
| 9 | $O_2$ AUTOGENOUS PRESSURANT EXPANDER |
| 10 | $O_2$ AUTOGENOUS PRESSURIZATION SHUT OFF VALVE PACKAGE |
| 11 | $LH_2$ SCREEN COOLANT EXPANDER |
| 12 | $LH_2$ SCREEN COOLANT SHUT OFF VALVE PACKAGE |
| 13 | $LH_2$ SCREEN COOLING HEAT EXCHANGER |
| 14 | $LH_2$ THERMODYNAMIC VENT SHUT OFF VALVE PACKAGE |
| 15 | $LH_2$ THERMODYNAMIC VENT COOLANT EXPANDER |
| 16 | $LH_2$ THERMODYNAMIC VENT HEAT EXCHANGER |
| 17 | LOX SCREEN COOLANT SHUT OFF VALVE PACKAGE |
| 18 | LOX SCREEN COOLANT EXPANDER |
| 19 | LOX SCREEN COOLING HEAT EXCHANGER |
| 20 | LOX THERMODYNAMIC VENT SHUT OFF VALVE PACKAGE |
| 21 | LOX THERMODYNAMIC VENT COOLANT EXPANDER |
| 22 | LOX THERMODYNAMIC VENT HEAT EXCHANGER |
| 23 | $LH_2$ ACPS FEED LINE HEAT EXCHANGER |
| 24 | LOX ACPS FEED LINE HEAT EXCHANGER |
| 25 | $LH_2$ LINE RELIEF VALVE PACKAGE |
| 26 | LOX LINE RELIEF VALVE PACKAGE |
| 27 | $LH_2$ TANK RELIEF VALVE PACKAGE |
| 28 | LOX TANK RELIEF VALVE PACKAGE |
| 29 | NON-PROPULSIVE OVERBOARD VENT |
| 30 | MODIFIED RL 10A-3-7 ENGINE |
| 31 | SUPERCRITICAL He TANK |
| 32 | SUPERCRITICAL TANK FILL |
| 33 | SUPERCRITICAL He REGULATOR VALVE PACKAGE |
| 34 | SUPERCRITICAL He HEAT EXCHANGER |
| 35 | SUPERCRITICAL He TANK RELIEF VALVE PACKAGE |
| 36 | AMBIENT He TANK |
| 37 | AMBIENT TANK FILL |
| 38 | AMBIENT TANK RELIEF VALVE PACKAGE |
| 39 | AMBIENT REGULATOR VALVE PACKAGE |

Fig. 4.3-2 OMS Schematic



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not be used during the OMS integrated testing. The feed system assembly test will be used to certify the pressure drop characteristics of the system, which is constrained in the integrated tests by placement of 100-ft $H_2$ lines in the altitude test facility. The cryogenic helium system performance will be certified during the assembly tests.

The OMS integrated test rig will consist of one PFC engine, a simulator set-up for the other engine, engine controller, OBC (if available), qualifiable propellant tanks ($LH_2$ and $LO_2$), and qualifiable feed, vent, pressurization, and ambient helium components. Use of an engine simulator allows testing and certification of the system for all two-engine operating conditions without the cost and complexity of firing two engines in the altitude chamber. Use of both oxygen tanks will ensure verification of the system for parallel flow operation. Complete testing of the OMS will be conducted with this rig, including:

- Engine firings, idle mode, and full thrust- on a complete subsystem level
- Feed system operation
- Autogenous pressurization capability
- Engine and feed system cool-down and thermal conditioning
- Repeatability of startup, shutdown, and idle mode characteristics
- Verification of onboard checkout and control system
- Verification of feed system, vent system, and pressurization system dynamics

The integrated test rig has a major role in certifying the OMS, as shown in Table 4.3-1. Start and operational sequences can be verified for all the OMS functions. These include (1) ready to fire operation for abort-to-orbit; (2) single engine startup in tank head idle mode during non-time critical on-orbit burns; and (3) backup engine pumped idle operation for the deorbit burn. The engine controller will be used to command these sequences. A second essential function of the integrated test rig is to certify the dynamic characteristics of the system, since assembly level testing would be inadequate. After its use for OMS certification, the integrated test rig will be used for the off-nominal and limit-type testing essential for the shuttle flight program.

A problem for integrated OMS testing involves the use of qualifiable flight-type hardware for the on-orbit tankage. Since these tanks are currently of the purge-bag type, rather than vacuum-jacketed dewar type tanks, the test rig will have to be placed inside a vacuum chamber with the capability of conducting engine hot firings. An altitude chamber such as the one existing at WSTF could be modified for use for the OMS integrated tests. The possible modifications would be to add a 20-foot extension to the WSTF chamber, place the on-orbit tanks, the feed and pressurization system, and the OMS engine inside the chamber, and build an enclosure around the engine to maintain the required vacuum for the tanks and to provide the capability to certify the OMS with engine hot firings; or to place the on-orbit tanks inside individual vacuum chambers, with the engine and feed system in the existing altitude chamber. Further investigation into the modifications and other available facilities is required to select the most cost-effective test facilities and techniques for the OMS certification program. It is noted that, if current trade studies indicate a baseline change to dewar tanks, vacuum requirements for the integrated test rig will be deleted.

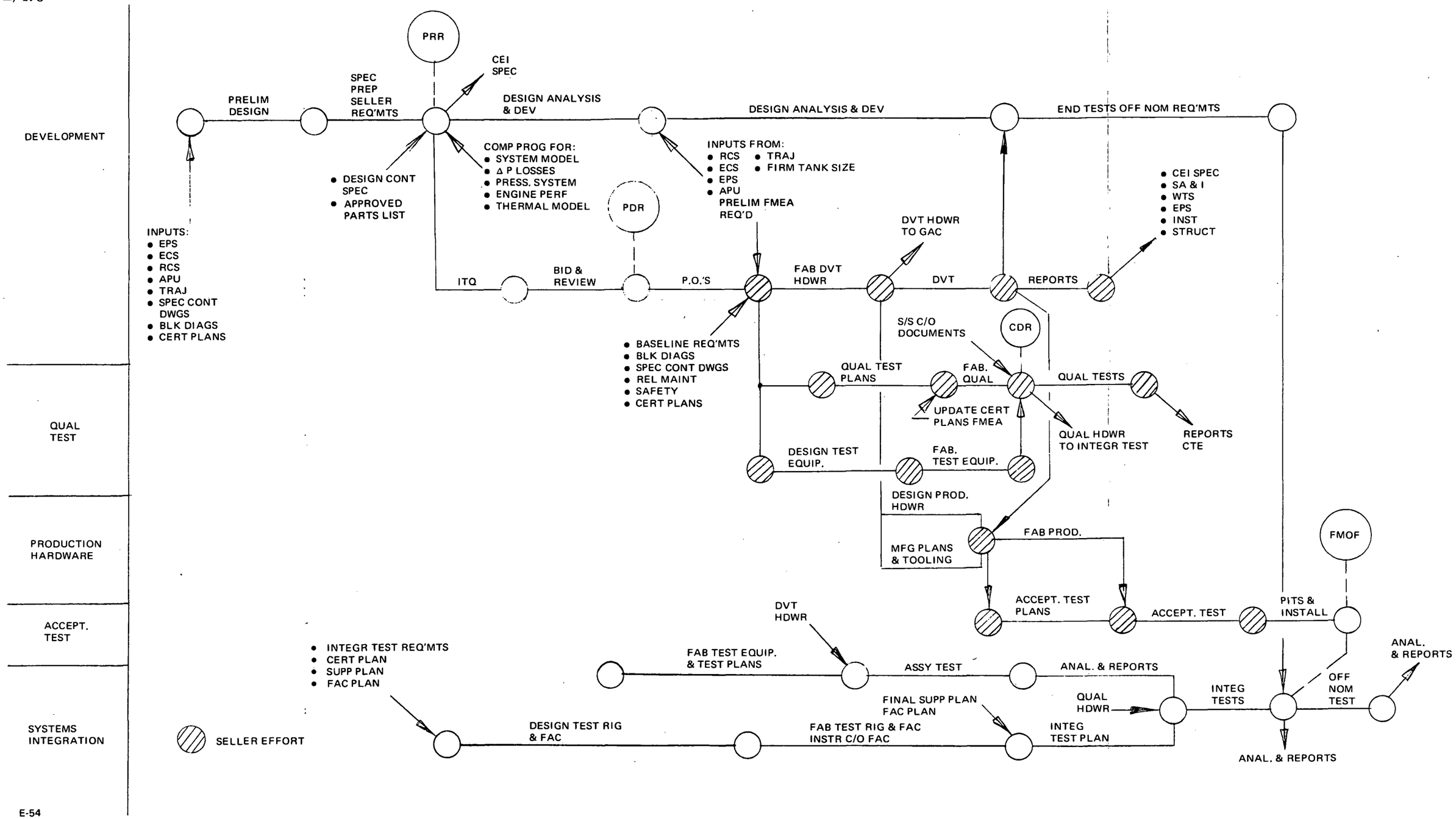


Fig. 4.3-3 Orbit Maneuvering System Logic Network



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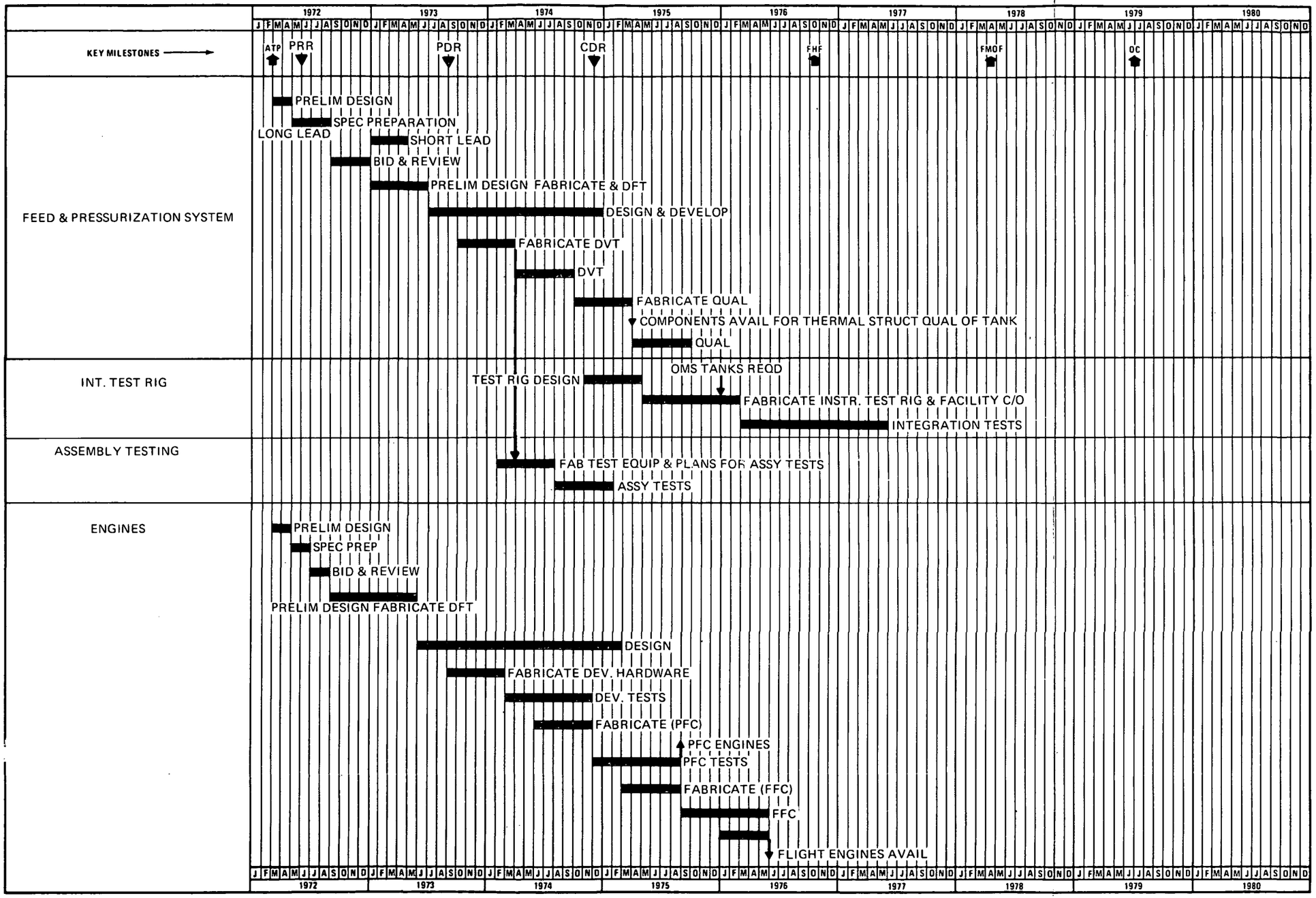


Fig. 4.3-4 On-Orbit Maneuvering System Schedule



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TABLE 4.3-1 ORBIT MANEUVERING SYSTEM - OMS
SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Demonstrate ability of fluid components (‡ ‡ ‡) to perform design function with correct ΔP and response | | | | | | X | X | | | | |
| • Demonstrate ability of fluid components to survive thermal, vibration and acceleration environments | | | | | | X | X | | | | |
| • Demonstrate fluid components life and cycle requirements | | | | | | X | X | | | | |
| • Demonstrate engine performance (thrust, Isp, start and shutoff transients) | | | | | | X | X* | | | | |
| • Demonstrate engine life and start requirements | | | | | | X | X | | | | |
| • Demonstrate ability of engine to withstand thermal, vibration, accoustic and acceleration environments | | | | | | X | X | | | | |
| • Demonstrate capability to cool down lines and engines using dump | | | | | | X | | | X** | | |
| • Demonstrate ability to cool down lines and start engines in tank head idle mode | | | | | | X | | | X | | |
| • Capability to use fixed engines (no gimbals) | X | | | | | | | | | | |

TABLE 4.3-1 ORBIT MANEUVERING SYSTEM - OMS
SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Demonstrate ability of subsystem, incl. engine controller to perform all necessary procedures (abort to once around, normal start, stand-by engine operation) | | | | | | X | | | X | | |
| • Demonstrate capability of thermal vent system to maintain subcooled liquid in tanks*** | | | | | | X | X | | | | |
| • Demonstrate capability of screen cooling and cold gas autog. press. systems to prevent screen dryout | | | | | | X | | | X | | |
| • Demonstrate ability of autogenous pressurization to provide required NPSH | | | | | | X | | | X | | |
| • Verify feed system pressure drop characteristics | X | | | | X | | | X‡ | | | |
| • Verify feed system/engine dynamic effects | X | | | | | X | | | X | | |
| • Demonstrate 2 tank $LO_2$ PU | | | | | | X | | | X | | |
| • Demonstrate MR control | | | | | X | | X* | | | | |
| • Demonstrate PU using MR control | X | | | | | X | | | X | | |
| • Demonstrate capability of system instrumentation and OBC equipment to perform their functions | | | | | | X | | | X | | |

TABLE 4.3-1 ORBIT MANEUVERING SYSTEM - OMS
SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Demonstrate capability of cryogenic He system to provide purge flow (for purge bags) at correct pressure temperature | | | | | | X | | X‡‡‡ | | | |
| • Demonstrate ability of ambient He tank to supply mission req'ts for valve actuation | X | | | | | | | | | | |
| • Demonstrate capability to service propellant, cryo He and ambient He tanks *** | | | | | X | | X | | | | |

‡‡‡Includes lines, valves, ht. exchangers, He tanks
‡‡Assembly consists of He tank, lines, valves, heat exchanger
‡Complete feed system assembly
***This CRT is part of tank testing
**Subsystem test is on integrated test rig
*Engine considered component

TABLE 4.3-2 OMS MAJOR COMPONENTS LIST
(Sheet 1 of 3)

| Section | Item | Description | Qty/ Veh | Weight Each | Size Each | Power Each |
|---|---|---|---|---|---|---|
| Storage | 1 | $LH_2$ tank (see Subsection 3.2 - fuselage & internal tanks) | 1 | 1482 | TBD | TBD |
| | 2 | $LH_2$ tank capacitance probe | 1 | incl. in 1 | TBD | TBD |
| | 3 | $LO_2$ tank (see Subsection 3.2 - fuselage & internal tanks) | 2 | 295 | TBD | TBD |
| | 4 | $LO_2$ tank capacitance probe | 2 | incl. in 2 | TBD | TBD |
| Feed | 5 | $LH_2$ tank shut off valve package | 1 | 28 | TBD | TBD |
| | 6 | $LO_2$ tank shut off valve package | 2 | 28 | TBD | TBD |
| Pressur-ization | 7 | $H_2$ autogenous pressurization shut off valve package | 1 | 14 | TBD | TBD |
| | 8 | $H_2$ autogenous pressurant expander | 1 | 1 | TBD | TBD |
| | 9 | $O_2$ autogenous pressurant expander | 2 | 1 | TBD | TBD |
| | 10 | $O_2$ autogenous pressurization shut off valve package | 2 | 19 | TBD | TBD |
| Vent | 11 | $LH_2$ screen coolant expander | 1 | 1 | TBD | TBD |
| | 12 | $LH_2$ screen coolant shut off valve package | 1 | 9 | TBD | TBD |
| | 13 | $LH_2$ screen cooling heat exchanger | 1 | 5 | TBD | TBD |
| | 14 | $LH_2$ thermodynamic vent shut off valve package | 1 | 9 | TBD | TBD |
| | 15 | $LH_2$ thermodynamic vent coolant expander | 1 | 1 | TBD | TBD |
| | 16 | $LH_2$ thermodynamic vent heat exchanger | 1 | 40 | TBD | TBD |

TABLE 4.3-2 OMS MAJOR COMPONENTS LIST
(Sheet 2 of 3)

| Section | Item | Description | Qty/ Veh | Weight Each | Size Each | Power Each |
|---|---|---|---|---|---|---|
| Vent (cont'd) | 17 | $LO_2$ screen coolant shut off valve package | 1 | 9 | TBD | TBD |
| | 18 | $LO_2$ screen coolant expander | 1 | 1 | TBD | TBD |
| | 19 | $LO_2$ screen cooling heat exchanger | 1 | 3 | TBD | TBD |
| | 20 | $LO_2$ thermodynamic vent shut off valve package | 1 | 9 | TBD | TBD |
| | 21 | $LO_2$ thermodynamic vent coolant expander | 1 | 1 | TBD | TBD |
| | 22 | $LO_2$ thermodynamic vent heat exchanger | 1 | 25 | TBD | TBD |
| | 23 | $LH_2$ ACPS feed line heat exchanger | 1 | 8 | TBD | TBD |
| | 24 | $LO_2$ ACPS feed line heat exchanger | 1 | 8 | TBD | TBD |
| | 25 | $LH_2$ line relief valve package | 1 | 5 | TBD | TBD |
| | 26 | $LO_2$ line relief valve package | 1 | 34 | TBD | TBD |
| | 27 | $LH_2$ tank relief valve package | 1 | 34 | TBD | TBD |
| | 28 | $LO_2$ tank relief valve package | 1 | 67 | TBD | TBD |
| | 29 | Non-Propulsive overboard vent | 10 | 2 | TBD | TBD |
| Engine | 30 | Modified RL10A-3-7 engine | 2 | 330 | TBD | TBD |
| Helium | 31 | Supercritical He tank | 1 | 170 | TBD | TBD |
| | 32 | Supercritical tank fill | 1 | 22 | TBD | TBD |
| | 33 | Supercritical He regulator valve package | 1 | 19 | TBD | TBD |
| | 34 | Supercritical He heat exchanger | 1 | 25 | TBD | TBD |



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TABLE 4.3-2 OMS MAJOR COMPONENTS LIST
(Sheet 3 of 3)

| Section | Item | Description | Qty/ Veh | Weight Each | Size Each | Power Each |
|---|---|---|---|---|---|---|
| Helium (cont'd) | 35 | Supercritical He tank relief valve package | 1 | 10 | TBD | TBD |
| | 36 | Ambient He tank | 1 | 180 | TBD | TBD |
| | 37 | Ambient tank fill | 1 | 18 | TBD | TBD |
| | 38 | Ambient tank relief valve package | 1 | 10 | TBD | TBD |
| | 39 | Ambient regulator valve package | 2 | 19 | TBD | TBD |

TABLE 4.3-3 REQUIRED EQUIVALENT UNITS
ORBITAL MANEUVERING SYSTEM (OMS)

| Hardware Description | ***Required Equiv. Units | | | | | |
|---|---|---|---|---|---|---|
| Flight hardware per vehicle | * | 1 | 1 | 1 | 1 | 1 |
| Component Devel & Qual test | * | 3 | 3 | 3 | 3 | 3 |
| Integration tests | | | | | | |
| • Full mission simulation lab | | | | | | |
| • Integrated avionics test lab | | | | | | |
| • Flight controls hydraulic test lab | | | | | | |
| • Mechanical systems test rigs | | | | | | |
| • Propulsion fluid ass'y tests | | 2 | | | | 2 |
| • Escape system test rig | | | | | | |
| Test articles | | | | | | |
| • Propulsion test article**** | 1 | 1-1/2 | 1-1/2 | 1-1/2 | 1 | 1-1/2 |
| • Structural test article | | | | | | |
| Spares for flight test program | * | 1/2 | 1/2 | 1/2 | 1 | 1/2 |
| Spares for 445 flights | * | 1 | 1 | 1 | 2 | 1 |
| Sections** | Storage | Feed | Press. | Vent. | Engine | Helium |

Notes:

**** OMS Integrated test rig

*** Numbers of equivalent units refer to ship-sets of hardware in each section

** For breakdown of sections refer to Table 4.3-2 (component list) and Fig. 4.3-1 (functional logic diagram)

* Storage section (OMS propellant tanks) not accounted for in this WBS for flight hardware or for component development and qualification or for spares for operational flights and flight test program. Refer to Subsection 3.2 (fuselage and internal tanks) WBS for hardware requirements for those categories.

TABLE 4.3-4 *ORBIT MANEUVERING SYSTEM (OMS)*
BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Sections | | | | |
| Storage | | | X | |
| Feed | | | X | |
| Pressurization | | | X | |
| Vent | | X | | Possible commonality with Booster ACPS vent components |
| Engine | | | X | |
| Helium | | X | | Possible commonality with any required helium system on Booster |

TABLE 4.3-5 ORBIT MANEUVERING SYSTEM (OMS)
SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Component and assembly testing<br>- Test benches for component and assembly testing; pressure, temp, flow monitoring and control equipment<br>- $LH_2$ & $LO_2$ supply equipment (50 psi)<br>- LHe supply and conditioning equipment (up to 3500 psi)<br>- Gas supply rig - up to 400 psi $H_2$ and $O_2$<br>up to 500 psi He |
| | • OMS integration testing<br>- $LO_2$ & $LH_2$ supply equipment<br>- LHe supply equipment<br>- Test control console<br>- Altitude firing capability for 800 sec with steam ejector vacuum system<br>- Instrumentation, data acquisition, control equipment to support integration tests, and engine hot firings |
| Software | • Computer programs for:<br>- Control tapes for sequencing and control of the OMS integrated test rig<br>- Data reduction |

TABLE 4.3-6 ORBIT MANEUVERING SYSTEM (OMS)
FACILITY REQUIREMENTS LIST

| Title & Description | New | Exist | Contr | Govt |
|---|---|---|---|---|
| • He- Test Benches & Facilities for: | | | | |
| - Warm Gas - Component testing of regulators, shut-off valves, accumulators, lines | | X | X | |
| - Cryogenic Liquid & Gas - Assembly testing of shut-off valves, vent/relief valves, heat xchgr, fill QDC, lines | | X | X | |
| • $O_2$ & $H_2$ - Test Benches & Facilities for: | | | | |
| - Cryogenic Liquid & Gas - Assembly testing of propellant feed system including lines, shut-off valves, control valves, relief valves | X | | X | |
| • Facility for Integrated Testing of OMS | | | | |
| - Facility must supply: Liq & Gas $O_2$, $H_2$ & He supply, Facility for hot firings of OMS engines - Altitude Simulation, Data reduction & acquisition req"d - for monitoring & control of complete integrated test program Require vacuum chamber ($10^{-5}$ Torr) to contain 1 $H_2$ and 2 $O_2$ tanks, feed, pressurization & vent system, one RL10 engine, one engine simulator - capability to fire engine while maintaining vacuum environment on tanks | | X | | X |

TABLE 4.3-7 COMPUTER SUPPORT REQUIREMENTS

| Computer programs will be utilized for: |
| --- |
| • Feed system pressure drops<br>• Feed system/engine dynamic effects<br>• Pressurization system performance<br>• OMS system model |

# 4.4 ATTITUDE CONTROL PROPULSION SYSTEM

## 4.4.1 SUBSYSTEM DESCRIPTION

The attitude control propulsion system provides all on-orbit orientation and attitude maneuvers, and all translational maneuvers except those assigned to the orbit maneuver system (OMS). In addition, the system provides conditioned hydrogen and oxygen for ECS, EPS, and APU. System design satisfies a fail operational/fail safe requirement. The major subsections are storage (common with OMS) and acquisition; conditioning modules and control units; regulation and distribution; and thrusters. Capillary screens in the on-orbit tanks guarantee saturated or subcooled liquid delivery from the tanks. Boost pumps in the storage system provide subcooled propellants to the turbine-driven pumps in the conditioning modules. High pressure propellant is passed through heat exchangers which raise the temperature to specified hydrogen and oxygen accumulator temperatures. The gas accumulators, which decouple thruster demand from supply tank demand, supply regulated propellants to the ACPS thrusters, to the turbine and heat exchanger gas generators in the conditioning modules, and to the other fluid systems. Control units detect accumulator refill requirements and sequence the startup, steady state, and shutdown operations of the conditioning module components. The units also detect and ensure safe shutdown in the event of a malfunction. The ACPS schematic is shown in Fig. 4.4-1.

### 4.4.1.1 Discussion

The ACPS plan for development of a flight system with a high degree of confidence is shown in Fig. 4.4-3 and 4.4-4. Extensive component evaluation and verification testing, and system analyses lead to a subassembly and subsystem test program with assured high level of success, allowing flight system buildup in parallel to the subsystem certification. Interfacing vehicle and system requirements are defined before program start and are available to permit early preparation of component specifications. The operational interface block diagram is shown in Fig. 4.4-2. Airframe locations are coordinated with the vehicle structural subsystem, and flight and ground test ACPS layouts are started.

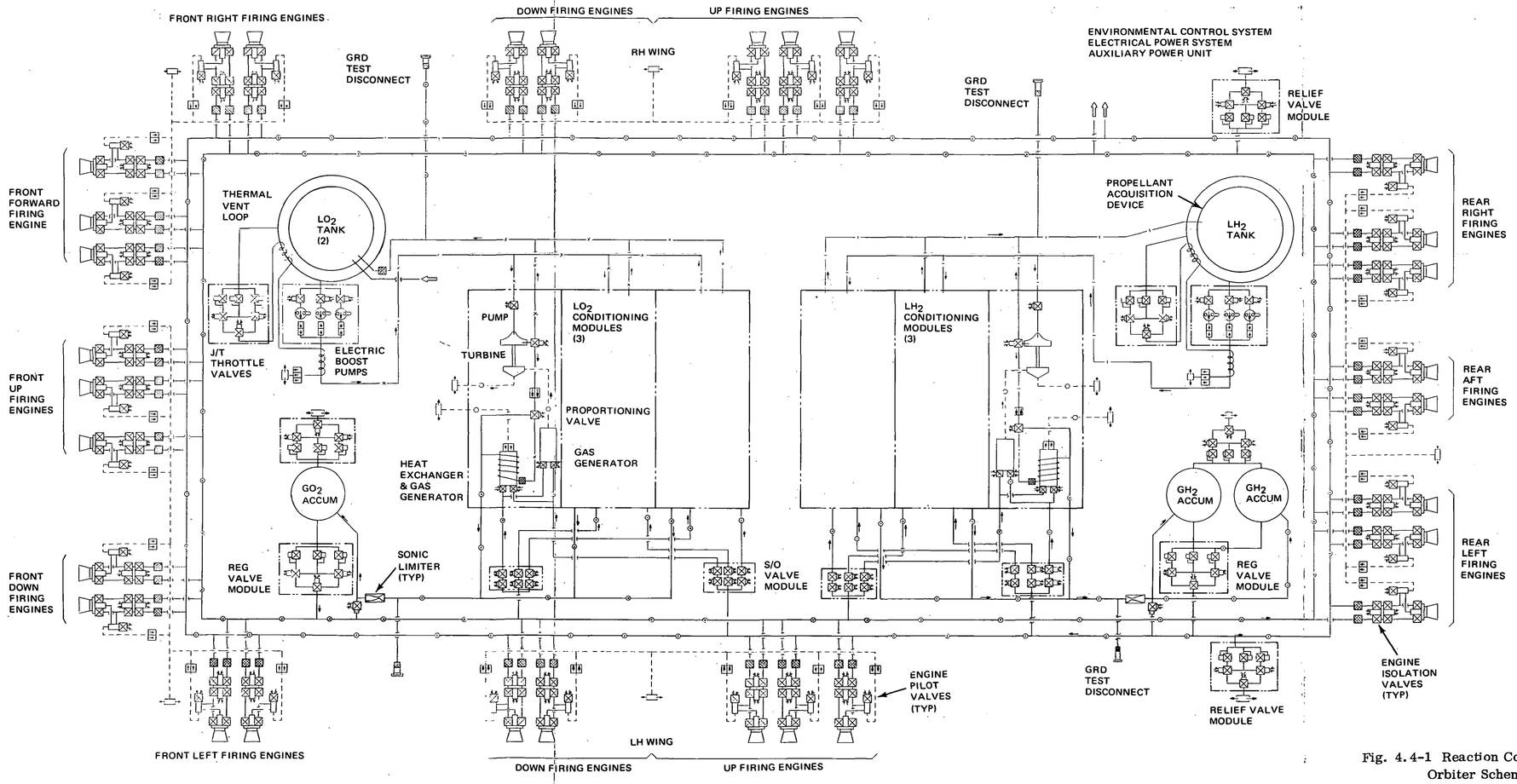


Fig. 4.4-1 Reaction Control System Orbiter Schematic



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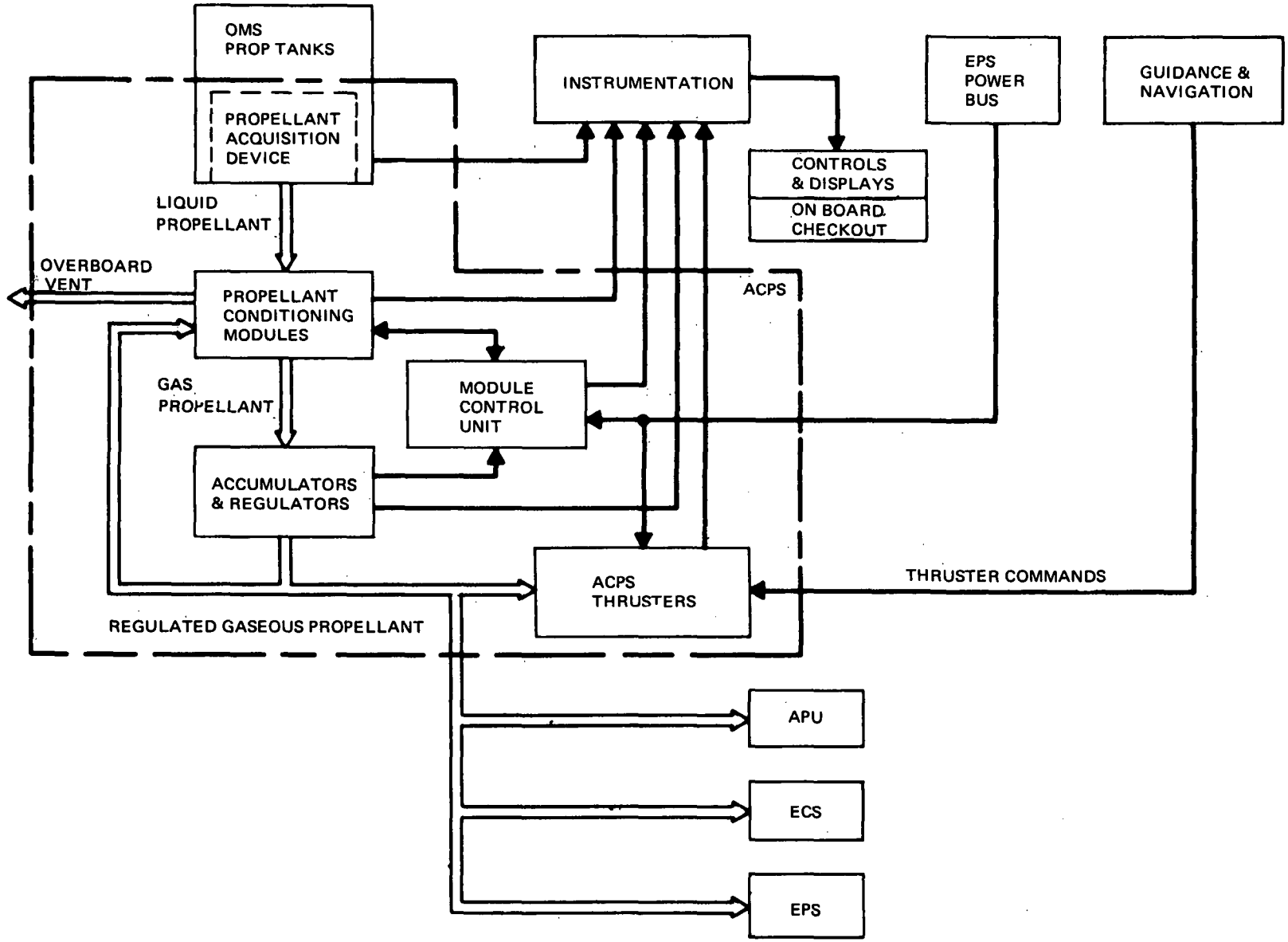




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Fig. 4.4-2 Attitude Control Propulsion System Operational Interface Block Diagram

Specification of long and short lead components is time-phased to minimize staffing. The development schedule of the turbopumps, which are the pacing long lead items, is detailed in Fig. 4.4-4. Specification preparation for other items is included as an indication of the scheduling of other components.

Other long lead items are the gas generators, heat exchangers, and thrusters. The schedule represents a reduced development cycle based on information being available from technology studies under contract to NASA before Phase C/D start. The specific required information, which would demonstrate design feasibility of key components and subcomponents, will be determined. It is estimated that availability of technology studies prior to program start reduces the normal development cycle 6 to 9 months.

The key analytical tools required to support component and system development are shown in Table 4.4-7. Additional information for program estimating is shown in Tables 4.4-2 and 4.4-3.

The liquid acquisition device and conditioning module control are the critical ACPS development areas. Feasibility of capillary screens, which are baselined for propellant acquisition, will not have been proven by Phase C/D go-ahead. Therefore, a bellows tank acquisition system is developed in parallel to reduce risk. Subscale -1G screen tests establish capability of liquid propellant retention and transfer, and analytical similarity techniques are used to correlate these tests to mission requirements. Technology contracts inputs plus subscale test results (Fig. 4.4-3) will be completed in sufficient time to permit development of the selected device. OMS tank internal interface requirements are defined at the decision point to allow time for propellant tank testing (subsection 3.2).

Conditioning system control development risk is resolved by minimizing design complexity and by dynamic analysis and test methods. The conditioning system design has separate gas generators for each turbine and heat exchanger. This feature simplifies module control in that component startup, shutdown, and operation can be sequenced. System stability, operating ranges, and control requirements are defined by system dynamic analysis, and feasibility is verified in the module tests.

Interaction of the system components and subassemblies is evaluated in three test programs. The first program comprises two separate development tests of the oxygen and

hydrogen conditioning modules to verify startup, shutdown, stability, performance, and control logic. The second program, run concurrently, evaluates the transient behavior of the gaseous hydrogen and gaseous oxygen feedlines using a representative portion of the flight distribution system under realistic system demands. System operating conditions which vary widely throughout the mission will be tested fully. The third program, which constitutes the only ACPS systems testing in the development plan, evaluates total system operating range using qualifiable units; integrates the subassemblies including oxygen and hydrogen conditioning modules and control units, accumulators, regulators, feed system, and thrusters; and evaluates off-limits system operation. The LM RCS program experience has shown that the last item, off-limits testing, was an important factor in broadening flight operational limits.

The first program test article consists of a hydrogen and an oxygen conditioning module (Fig. 4.4-1) each of which is tested separately. The alternate gas generator propellant (for example, hydrogen for the oxygen conditioning module) is supplied from a GSE accumulator, and the conditioned propellant is collected in another GSE accumulator to be fed to the gas generators. Each module (approximately 1.5 ft x 3 ft x 5 ft) will use hardware from component development programs identical to that used for component DVT.

The second program test article consists of a portion of the ACPS gaseous propellant feed system including accumulators, regulators, and feed system and thruster injector valves. The hydrogen and oxygen units are tested separately. Components rated for DVT are used.

Following the subassembly tests, a subsystem test article is built up and tested. The article, which consists of the dynamic operational portion of the subsystem plus one redundant set of conditioning modules for off limits and malfunction tests, has two hydrogen and two oxygen conditioning modules, a control unit for each module, one hydrogen and one oxygen accumulator, feed system regulator and relief units, feed lines, seven sets of isolation valves, and seven thrusters. Items salvable from the subassembly development programs will be used. All components will be qualifiable, flight hardware and the test will form the basis for subsystem certification. As testing progresses and components integrate successfully, the go-ahead will be given for flight hardware fabrication. Each

deviation from the flight shipset configuration is justifiable from a technical and economic viewpoint. For example, a maximum thrust demand of less than 7 equivalent thrusters is expected for the 30 thruster system. The tankage interface requirement (propellant conditions to the boost pump) is clearly defined and relatively static; therefore, GSE tankage required for module tests will be used. RCS/OMS integration testing is also excluded because the tanks are the only point of commonality. OMS flow demand effects will be simulated. Flight tankage is fully certified by the vehicle structures subsystem. All subassembly and subsystem testing will be run at a government test facility such as White Sands Test Facility, New Mexico. Facility, support, and software requirements for the test programs are shown in Tables 4.4-5 and 4.4-6.

ACPS certification requirements are shown in Table 4.4-1. The certification method and level of assembly indicated are for planning purposes only and will be finalized after program go-ahead. Each unit will be certified at the component level. In some cases, additional certification will be made with the component installed at the next assembly level and interfacing with other subassemblies. For example, the turbopump is certified upon satisfactory completion of its component qualification test, and additional certification testing will be performed with the adjacent components (boost pumps, heat exchangers, and gas generators) and adjacent subassemblies (module control unit and onboard checkout). The interfaces can be real or simulated. Endorsement of the component certification constrains subsystem certifications, which in turn constrain the FMOF.

Current orbiter and booster ACPS use non-common thrusters and conditioning systems (Table 4.4-4). However, evaluation of system requirements are continuing, and the penalties and benefits of using partial or total commonality will be evaluated. Many lesser components may have only size difference and are certified by similarity.

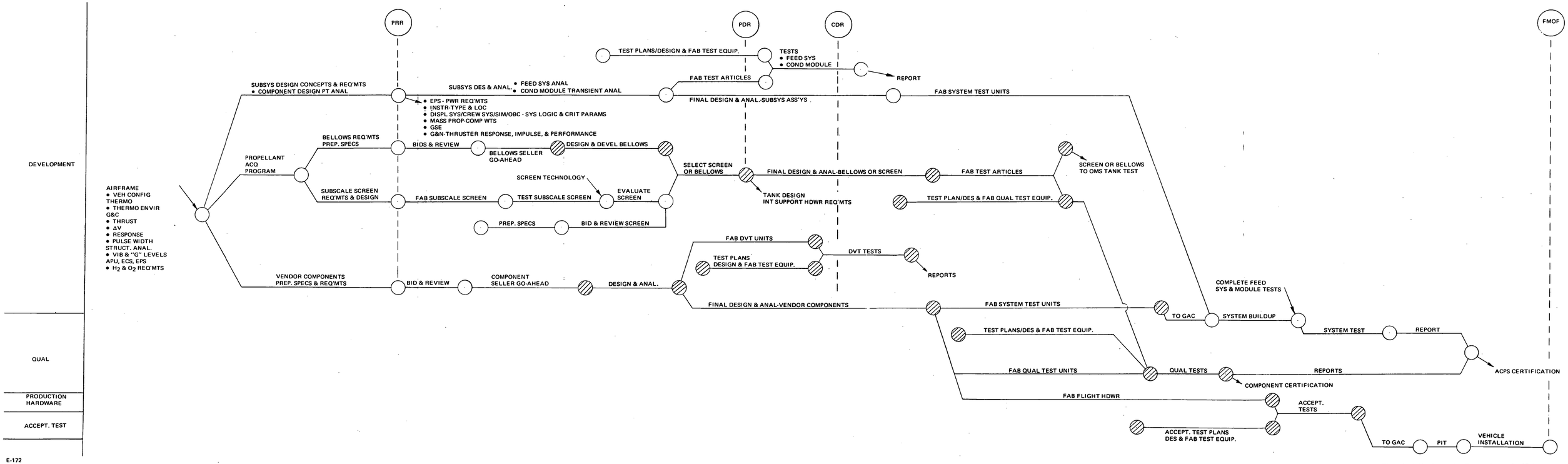


Fig. 4.4-3 Attitude Control Logic Network



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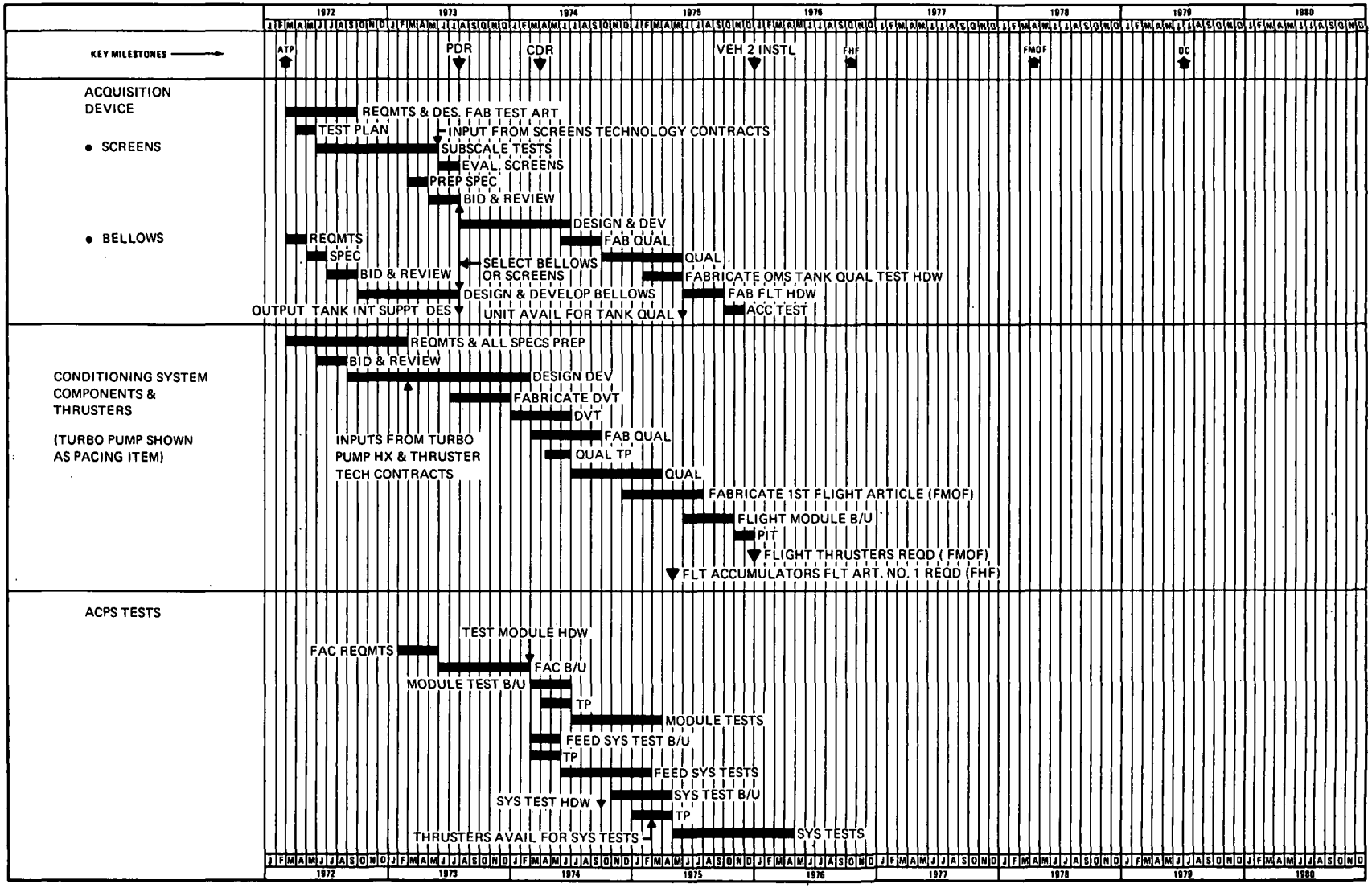


Fig. 4.4-4 Attitude Control Propulsion System



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BOEING

TABLE 4.4-1 ATTITUDE CONTROL PROPULSION SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 1 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Use | DVT | Qual | Component | Assy | Subsystem | Com Subsys | Flt Veh |
| • Components | | | | | | | | | | | |
| - $LH_2$ & $LO_2$ tank outlet boost pump | | | | | | X | X | | X | | |
| - $LH_2$ & $LO_2$ turbopump and gas generator | | | | | | X | X | | X | | |
| - $LH_2$ & $LO_2$ heat exchanger and gas generator | | | | | | X | X | | X | | |
| - $GH_2$ & $GO_2$ accumulators | | | X | | | | X | | X | | |
| - $GH_2$ & $GO_2$ pressure regulator | | | | | | X | X | | | | |
| - $LH_2$ & $LO_2$ shut-off valves | | | | | | X | X | | | | |
| - $LH_2$ & $LO_2$ propellant acquisition devices | | | | | | X | X | | | | |
| - $LH_2$ & $LO_2$ fill and drain disconnect | | | X | | | | X | | | | |
| - $LH_2$ & $LO_2$ check valves | | | | | | X | X | | | | |
| - $LH_2$ & $LO_2$ filters | | | X | | | | X | | | | |
| - $H_2$ & $O_2$ vent valves | | | | | | X | X | | | | |
| - $GH_2$ & $GO_2$ check valves | | | X | | | | X | | | | |
| - $GH_2$ & $GO_2$ filters | | | X | | | | X | | | | |
| - Propellant conditioning module control units | | | | | | X | X | X | X | | |
| - Pressure transducers | | | | X | | | X | | | | |
| - Temperature transducers | | | | X | | | X | | | | |

TABLE 4.4-1 ATTITUDE CONTROL PROPULSION SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 2 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Use | DVT | Qual | Component | Assy | Subsystem | Com Subsys | Flt Veh |
| - $GH_2$ & $GO_2$ relief valves | | | | | | X | X | | | | |
| - Plumbing expansion joints | | | X | | | | X | X | | | |
| - Ball joints | | | X | | | | X | X | | | |
| - Engine isolation valves | | | | X | | | X | | | | |
| - Test disconnects | | | X | | | | X | | | | |
| - Sonic limiter | | | | | | X | X | | X | | |
| - Bypass valves | | | | | | X | X | | X | | |
| - $GH_2$ & $GO_2$ selector valves | | | | | | X | X | | | | |
| • General | | | | | | | | | | | |
| - Capability of ACPS to provide required control impulse | X | | | | X | | | | X | | |
| - Capability of ACPS to provide required control response | X | | | | X | | | | X | | |
| - Capability of ACPS to withstand vibration and acoustic effects from MPS operation | X | | | | | X | X | | | | |
| - Ability of ACPS to withstand space environment effects | X | | | | | X | X | | | | |
| - ACPS capability to withstand main propulsion engine base heating effects | X | | | | | X | X | | | | |

TABLE 4.4-1 ATTITUDE CONTROL PROPULSION
SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 3 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Use | DVT | Qual | Component | Assy | Subsystem | Com Subsys | Flt Veh |
| - Capability of ACPS to operate after long periods of on-orbit inactivity | X | | | | X | | | | X | | |
| • Propellant storage and feed assembly | | | | | | | | | | | |
| - Ability to provide propellant to the turbopump inlets at the required condition (temp & press.) | | | | | | X | X | | X | | |
| - Capability to monitor and evacuate vacuum jacket feed lines | | | | | | X | X | X | | | |
| - Compatibility of propellant fill and drain servicing/distribution lines | | | | | X | | | X | X | | |
| • Propellant conditioning and distribution assembly | | | | | | | | | | | |
| - Capability of $H_2$ & $O_2$ gas generators and heat exchanger assemblies to provide sufficient conditioned propellant for attitude-control thrusters and gas generator operations | | | | | | X | X | X | X | | |
| - Capability of $O_2$ & $H_2$ conditioning modules to provide propellants to the accumulators and regulators at specified conditions and response | | | | | X | | | X | X | | |
| - Ability of $O_2$ and $H_2$ accumulator vent and relief assemblies to maintain the accumulator pressure below the maximum allowable | | | | | | X | X | X | | | |

TABLE 4.4-1 ATTITUDE CONTROL PROPULSION SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 4 of 4)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Use | DVT | Qual | Component | Assy | Subsystem | Com Subsys | Flt Veh |
| - Capability of accumulators to provide the required impulse to the attitude control thrusters | X | | | | | X | X | | X | | |
| • Attitude control thruster assemblies | | | | | | | | | | | |
| - Capability of the AC thruster to provide proper performance and response | X | | | | | X | X | | | | |
| - Ability to perform within vehicle thermal environments | X | | | | | X | X | | | | |
| - Ability of AC thrusters to withstand vibration environment | | | | | | X | X | | | | |
| - Ability to leak check engine/vehicle interfaces | | | | | X | | | | X | | X |
| • GSE | | | | | | | | | | | |
| - Compatibility of ACPS with GSE interfaces | | | | | X | | | | X | | |

TABLE 4.4-2 ATTITUDE CONTROL PROPULSION SYSTEM
MAJOR COMPONENT LIST

| Comp No. | Component Description | Qty/ Veh | Unit Wt (Lbs) | Unit Size | Remarks |
|---|---|---|---|---|---|
| 1 | Capillary screen assembly - $H_2$ | 1 | 180.0 | | These components represent long lead development items and/or items that affect orbiter internal layout. |
| 2 | Capillary screen assembly - $O_2$ | 1 | 70.0 | | |
| 3 | Turbine driven pump - $H_2$ | 3 | 15.4 | 6" dia | |
| 4 | Turbine - $H_2$ | 3 | | 6" dia | |
| 4 | Turbine driven pump - $O_2$ | 3 | 9.7 | 5" dia | |
| 6 | Turbine - $O_2$ | 3 | | 5" dia | |
| 7 | Gas generator $H_2$ turbopump | 3 | 10.0 | 3" dia | |
| 8 | Gas generator $O_2$ turbopump | 3 | 8.3 | 3" dia | |
| 9 | Gas generator $H_2$ heat exchanger | 3 | 11.7 | 4" dia | |
| 10 | Gas generator $O_2$ heat exchanger | 3 | 10.0 | 4" dia | |
| 11 | $H_2$ heat exchanger | 3 | 25.0 | 6" x 30" | |
| 12 | $O_2$ heat exchanger | 3 | 20.0 | 6" x 25" | |
| 13 | $GH_2$ accumulator | 2 | 394.5 | 37.5 $ft^3$ | |
| 14 | $GO_2$ accumulator | 1 | 236.0 | 22.4 $ft^3$ | |
| 15 | Engine assembly | 30 | 26.0 | 10" x 25" | |
| 16 | Conditioning module control unit | 6 | TBD | TBD | |

TABLE 4.4-3 REQUIRED EQUIVALENT UNITS
ATTITUDE CONTROL PROPULSION SUBSYSTEM

| Hardware Description | Required Equiv Units |
|---|---|
| Flight hardware per vehicle | 1 |
| Component devel & qual test | 2 |
| Integration tests | |
| • Full mission simulation lab | |
| • Integrated avionics test lab | |
| • Flight controls hydraulic test lab | |
| • Mechanical systems test rigs | |
| • Propulsion fluid breadboards | |
| • Escape system test rig | |
| Test articles | |
| • Propulsion test article* | 1/2 |
| • Structural test article | |
| Spares for flight test program | 1/2 |
| Spares for 445 flights | 4 |

*Subassembly and subsystem tests

Equivalent units estimate is based on the following:

| Component | Flight (shipset) | Comp Dev and Qual | System Tests | Spares for Ops | Spares for Flt Test |
|---|---|---|---|---|---|
| Turbopump/GG | 6 | 18 | 4 | 30 | 4 |
| Heat exchanger/GG | 6 | 18 | 4 | 30 | 4 |
| Boost pump | 6 | 18 | 2 | 30 | 2 |
| Accumulator | 2 | 6 | 2 | 6 | 2 |
| Thruster | 30 | 30 | 7 | 60 | 6 |
| Equiv unit | 1 | 2 | 1/2 | 4 | 1/2 |





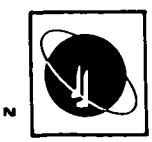


TABLE 4.4-4 ATTITUDE CONTROL PROPULSION SYSTEM
BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Attitude control thruster | | X | | Orbiter thrust = 1000 lb; Booster thrust = 2800 lb |
| Gaseous prop. regulators | | X | | |
| Propellant shutoff valves | | X | | |
| Engine isolation valves | | X | | |
| Check valves | | X | | |
| Test disconnects | | X | | |
| Relief valves | | X | | |
| Propellant gas filters | | X | | |
| Plumbing expansion joints | | X | | Dependent on similarity of line runs. May be common supplier. |
| Ball joints | | X | | |
| Filters | | X | | |
| Propellant Conditioning module including turbopump, heat exchanger & gas generator | | X | | Present booster uses supercritical storage conditioning concept |
| Accumulators | | X | | |
| Propellant selector valves | | X | | |

TABLE 4.4-5 ATTITUDE CONTROL PROPULSION SYSTEM
SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Test control consoles ($GO_2$, $GH_2$, $LO_2$, $LH_2$)<br>• Data monitoring/acquisition/reduction systems<br>• Test rig support frames<br>• Gaseous propellant collection and ducting system<br>• Hot exhaust gas collection and ducting system<br>• Sampling equipment (cleanliness, moisture content)<br>• Test rig flush and purge system<br>• GHe/$GH_2$ mass spectrometer leak detector<br>• Safety equipment |
| Software | • Computer program to control engine valve actuation and engine firing sequences<br>• Computer program to control conditioning module operating sequence |

TABLE 4.4-6 ATTITUDE CONTROL PROPULSION SYSTEM
FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Govt |
|---|---|---|---|---|
| • Conditioning module test | | X | | X |
| - Propellant conditioning modules ($H_2$ & $O_2$) tested separately in an ambient air conditioned cell. Liquid propellant from facility supply. Gaseous propellant collected in facility accumulators (hydrogen and oxygen). Facility dewar $LO_2$ & $LH_2$ tanks are used | | | | |
| - Floor space 20' x 20'. Power reqts: TBD. Data acquisition: multi-channel system with on-line computer, plotter, printer. 50-channel real time display | | | | |
| • Feed line test | | X | | X |
| - Propellant feed lines for 7 thrusters tested in ambient air conditioned cell. Separate tests for $H_2$ & $O_2$ systems. Gas accumulator charged from facility supply. Propellant discharged through engine valves collected and ducted outside | | | | |
| - Floor space 40' x 80'. Power reqts: TBD . Data acquisition same as above | | | | |
| • System integration test | | X | | X |
| - Complete propellant conditioning. Feed lines for 7 thrusters and 7 firing thrusters tested in ambient air conditioned cell. Facility liquid propellant supply. Exhaust from thruster firing ducted and collected. Facility dewars from module test are used. | | | | |
| - Floor space 60' x 90'. Power reqts: TBD. Data acquisition same as above except 100 channel real time display | | | | |

TABLE 4.4-7 COMPUTER SUPPORT REQUIREMENT - KEY PROGRAMS ATTITUDE CONTROL PROPULSION SYSTEM

- Component performance, design point analysis, weight tradeoff
  - Turbopump/gas generator
  - Heat exchanger/gas generator
  - Thruster
  - Gas accumulator
- Propellant conditioning module transient and steady-state analyses. Program to include component performance and controls characteristics
- Propellant feed system design and analysis

AVIONICS

Section 5

# INTEGRATED AVIONICS SYSTEM

The engineering and development plans for the integrated avionics system are described in the following section in terms of the Level 5 elements of the work breakdown structure (WBS). These elements are:

- Guidance, navigation, and control
- Data management
- Instrumentation (operational and development flight)
- Telecommunications/air traffic control
- Displays and controls
- Avionics subsystem design

A simplified block diagram (see Fig. 5-1) illustrates the major elements of the integrated avionics system. The system makes maximum use of 1972 MIL-E-5400 production hardware operating in a pressurized environment. The majority of functions are implemented to provide a fail operational/fail safe (FO/FS) capability. However, certain critical functions are selectively implemented to provide a FO/FO/FS capability. There are two separate computer complexes, with independent data buses and their associated remote acquisition and command units (RACU) for each. The flight critical and rapid reconfiguration functions are contained within a FO/FO/FS computer complex with quad redundant data buses and RACU's. The remaining functions are contained within a FO/FS computer complex with triply redundant data buses and RACU's. The RACU's interface with the equipments on a regional/geographic basis. The orbiter is operable by one crewman, although carrying a two-man crew. The major man-machine interface is via multipurpose cathode ray displays and data entry keyboards.

Additional integrated avionics subsystem details are presented in the following sections. This includes block diagrams, equipment lists, certification requirements, commonality candidates, logic and constraints networks, and bar chart schedules.

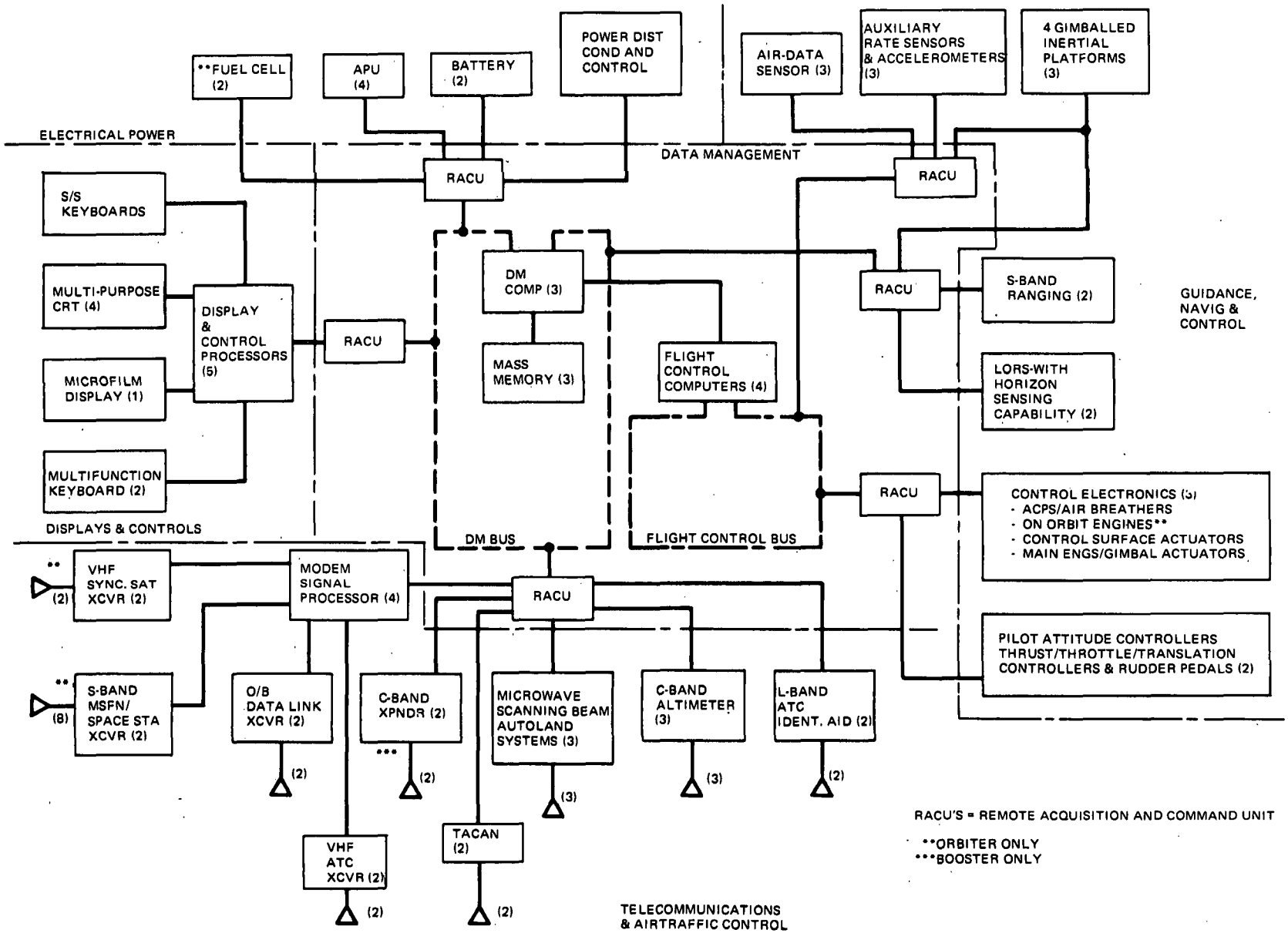


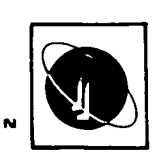

Fig. 5-1 Principal Elements of Integrated Avionics System

E/5

Power distribution, conditioning, and control are discussed in Section 6 (Power). An electromagnetic compatibility plan is presented in subsection 2.18. Pyrotechnic devices are discussed in subsection 3.9. Avionics ground tests are discussed in subsections 2.14 (Simulation) and 10.0 (Systems Ground Tests).







# 5.1 GUIDANCE NAVIGATION AND CONTROL

## 5.1.1 GUIDANCE NAVIGATION AND CONTROL DESCRIPTION

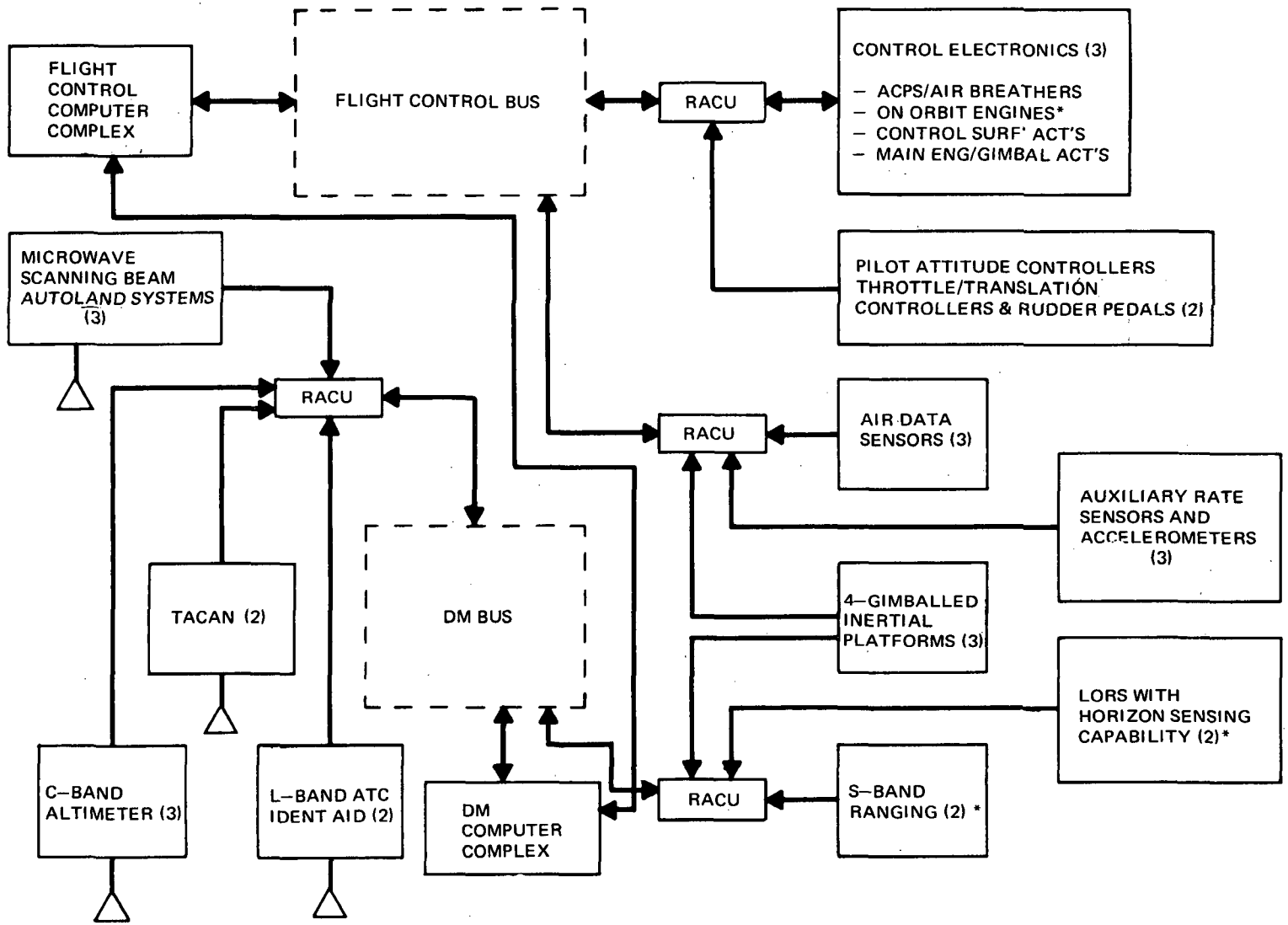
The GN&C system configuration meets the requirements for all shuttle orbiter mission phases. This configuration, depicted in Fig. 5.1-1, consists of the following major equipment groups: inertial measurement unit, orbital navigation equipment, terrestrial (rf) navigation equipment, automatic approach and landing equipment, and control electronics. Table 5.1-1 is a major component equipment list for this configuration.

Principal elements, features, and design characteristics of this configuration include:

- Digital stability augmentation and autopilot system for all mission phases
- Inertial measurement unit: multiple 4-gimballed inertial platforms
- Automatic approach and landing: microwave scanning beam system
- Terrestrial navigation aids:
  - TACAN
  - Radar altimeter
  - Air data sensor
  - ATC transponder
- Orbital rendezvous ranging - S-band ranging system
- Rendezvous - LOS beacon angle track
- IMU alignment - star track
- Orbit navigation update - horizon track

} Modified LM optical rendezvous system

- Auxiliary rate sensors and accelerometers which are dictated by aerodynamic flight control stability augmentation requirements




*ORBITER ONLY



Fig. 5.1-1 Guidance, Navigation & Control Subsystem

- Computation: flight control computer complex and
  data management computer complex

The principal motivation for the selection of this hardware complement has been to reduce program costs by minimizing GN&C equipment development risk. As a result, GN&C equipment will be derived (where possible) from existing military or commercially available designs (TACAN, IMU, air data, etc.). Hardware modifications will be required to accommodate and adapt this equipment to unique shuttle design requirements (e.g., automatic onboard checkout, coldplate cooling provisions, etc.).

The logic and constraint network shown in Fig. 5.1-2 identifies key development, qualification, production, acceptance, and system integration activities, milestones, and constraints.

The development issues that will have the most significant impact on the successful execution of the plan are:

- Implementation of hardware and software for the digital fly-by-wire flight control system
- Integration and interface compatibility of the GN&C avionics equipment with other space shuttle systems
  - Data management - multiplex data bus
  - Propulsion - main, ACPS, airbreathing, OME
  - Control surface actuators
- Choice and adaptation of existing commercial/military 4-gimballed inertial platforms for space shuttle utilization
- Selection of most cost-effective orbital and terrestrial navigation update technique. Trade-off between multi-functional precision ranging system and present baseline S-band ranging/TACAN/microwave scanning beam

Detailed technical studies with respect to GN&C design and development issues are discussed in depth in Volume I - Technical Summary - Final Report.

Engineering and development schedule data for the GN&C subsystem are presented in Fig. 5.1-3. This schedule identifies the following two separate GN&C development activities:

- GN&C equipment procurement, development, and test
- GN&C hardware/software integration test program

"Serial scheduling" will enable all design changes that result from a rigorous step-stress design verification test program to be incorporated into the final production design before the fabrication of qualification and production equipment. This approach, which has had some implementation on Grumman's present Navy programs (F-14A, E-2C, EA-6B), will significantly reduce the number of design deficiency problems that can be expected during qualification tests.

The hardware/software integration test program - a closed-loop complete mission dynamic simulation - will provide the necessary confidence and hardware/software interface verification prior to the first horizontal and FMOF flights. Grumman's Apollo LM experience indicates the importance of this type of testing. Iron Bird integration-hydraulics/actuators - with the GN&C hardware and software - will also augment interface verification.

Table 5.1-2 summarizes the GN&C subsystem certification requirements. These requirements have been identified with respect to expected constraints on first horizontal flight, FMOF, and IOC. The requirements are classified based on method of certification and level of assembly.

Table 5.1-3 lists the necessary GN&C subsystem equivalent units based on flight article, development test, integration test, and spare requirements.

GN&C subsystem support equipment/software requirements are summarized in Table 5.1-4. Requirements are categorized as follows: operations, integration testing, IATS, and vendor development testing.

GN&C booster/orbiter commonality candidates list and GN&C facilities requirements are described in Tables 5.1-5 and 5.1-6. Computer support requirements are contained in subsection 10.6.

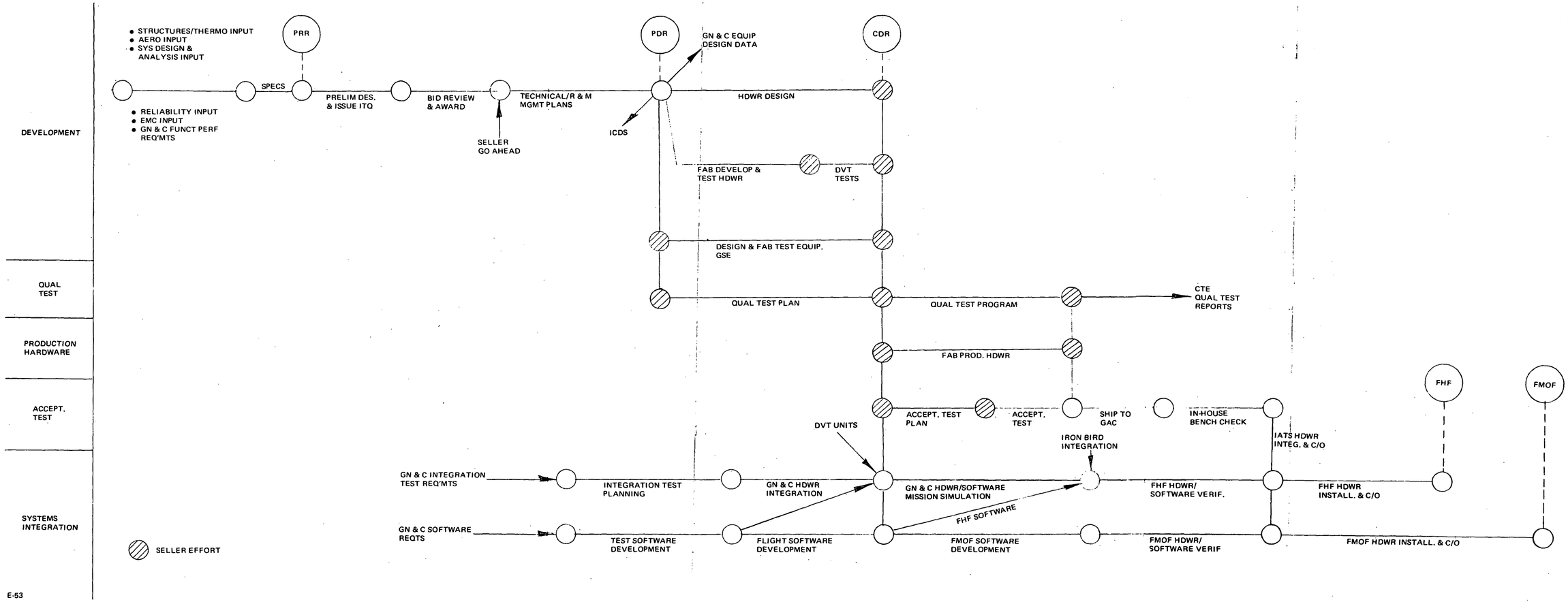



Fig. 5.1-2 Guidance, Navigation and Control Logic Network



GRUMMAN BOEING

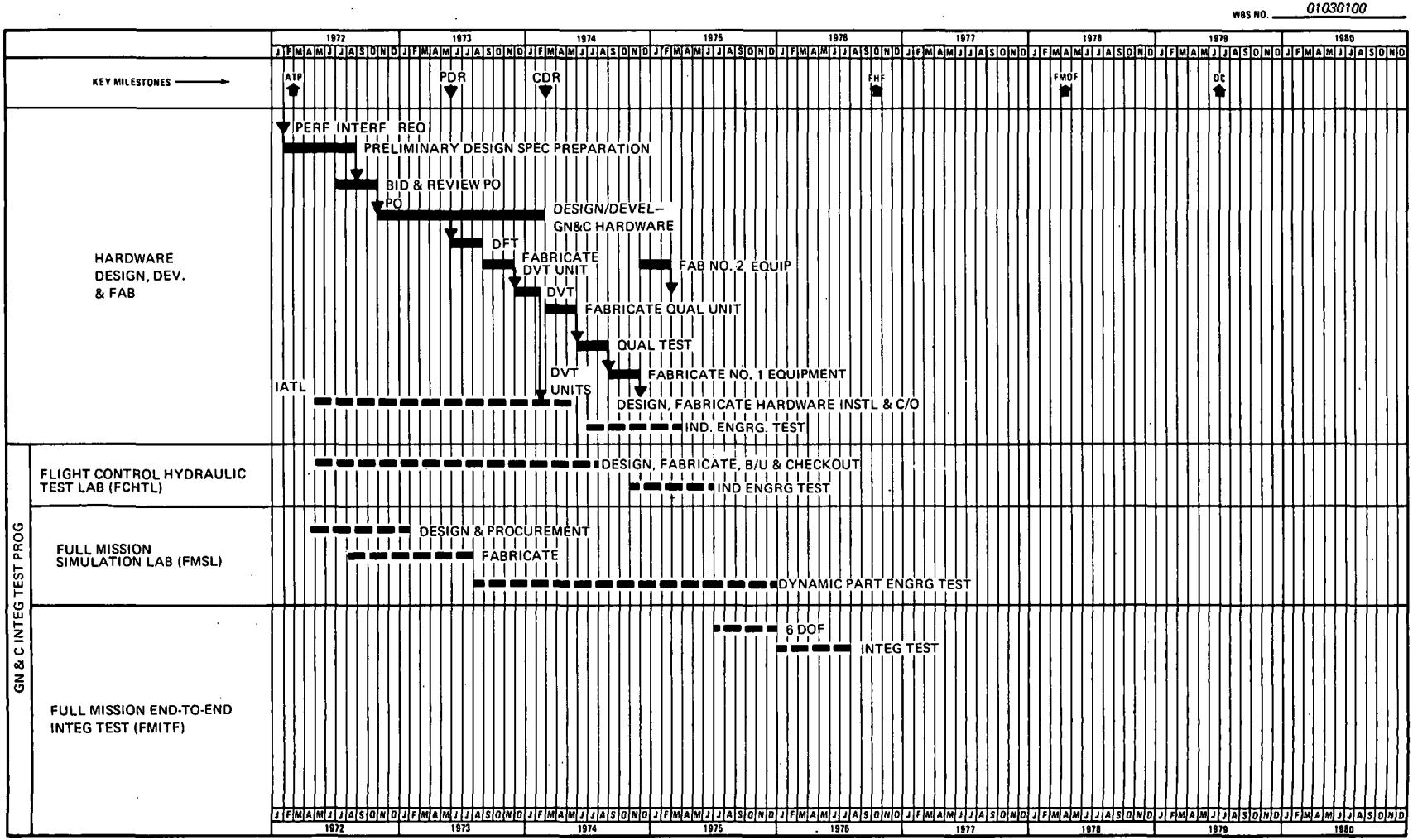



Fig. 5.1-3 Avionics Guidance Navigation & Control Schedule

TABLE 5.1-1. GUIDANCE NAVIGATION AND CONTROL - MAJOR COMPONENT EQUIPMENT LIST

| Equipment | Qty/ Vehicle | Unit Weight (Lb) | Unit Size (Cu.in.) | Unit Power (Watts) |
|---|---|---|---|---|
| • 4-gimballed inertial platform | 3 | 57 | 1552 | 150 |
| • Optical tracker modified LORS | 2 | 27 | 1000 | 40 |
| • Air data sensor | 3 | 6 | 54 | 20 |
| • Control electronics | | | | |
| - Elevon surfaces control | 3 | 8 | 225 | 20 |
| - Rudder surfaces control | 3 | 8 | 225 | 20 |
| - ABE control | 3 | 8 | 225 | 20 |
| - OME control | 3 | 8 | 225 | 10 |
| - Main engine control | 3 | 4 | 100 | 10 |
| - ACPS control | 3 | 10 | 225 | 15 |
| • Navigation and Landing | | | | |
| - C-band altimeter | Refer to telecommunications and air traffic control section | | | |
| - TACAN | | | | |
| - S-band ranging | | | | |
| - Microwave scanning beam | | | | |
| - L-band ATC transponder | | | | |
| • Computation | | | | |
| - Flight control computer complex | Refer to data management section | | | |
| - DM computer complex | | | | |
| • Auxiliary rate sensors and accelerometers (nose/tail installations) | 3 ea. | 3 | 50 | 20 |
| | | 3 | 50 | 4 |

TABLE 5.1-2. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 1 of 7)

| Reference: Space Shuttle Avionics System Technical Requirements Document B-35-16-MO-17-25 Feb 1971<br>Legend: H ≡ Constraint on 1st Horiz. Flight<br>V ≡ Constraint on FMOF<br>I ≡ Constraint on IOC<br>Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Operational Requirements | | | | | | | | | | | |
| - Pre-launch - Capability of being initialized and aligned for launch within TBD hours (I) | X | X | | | | | | | | X | |
| - Earth launch - Capability of performing all GN&C tasks from lift-off to orbit insertion - including aborts (V) | X | X | | | | | | | | X | |
| - Earth Launch - Capability of orienting recoverable stage (booster) to entry attitude after staging (V) | X | X | | | | | | | | X | |
| - Orbital (orbiter only) - Capability of performing onboard orbital navigation (V) | X | X | | | | | | | | X | |
| - Orbital (orbiter only) - Capability of onboard targeting and executing deorbit/landing point maneuvers (V) | X | X | | | | | | | | X | |
| - Orbital (orbiter only) - Capability of targeting and executing rendezvous maneuvers - cooperative targets (I) | X | X | | | | | | | | X | |
| - Orbital (orbiter only) - Provide capability for stationkeeping with cooperative targets (I) | X | X | | | | | | | | X | |
| - Orbital (orbiter only) - Capability for docking with a cooperative space station/base (I) | X | X | | | | | | | | X | |

TABLE 5.1-2. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 2 of 7)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| - Entry and transition - Provide capability for properly controlling vehicle through reentry and $\alpha$ transition (V) | X | X | | | | | | | | X | |
| - Approach and landing - Provide capability of properly guiding and controlling vehicle thru final approach (H) | X | X | | | | | | | | X | |
| - Landing - Provide automatic landing capability at selected landing sites (H) | X | X | | | | | | | | X | |
| - Landing - Provide a single go-around capability (H) | X | X | | | | | | | | X | |
| - Ferry - Provide capability of executing ferry operations - take-off/landing (H) | X | X | | | | | | | | X | |
| - Aborts - Capability of controlling and guiding vehicle(s) to insure safe aborts (I) | X | X | | | | | | | | | |
| • Operating Modes - Demonstration of functional capability | | | | | | | | | | | |
| - Automatic modes | | | | | | | | | | | |
| o Pre-launch calibration and alignment (V) | X | X | | | | | | | | X | |
| o In-flight calibration and alignment (I) | X | X | | | | | | | | X | |
| o Earth launch guidance and control (V) | X | X | | | | | | | | X | |

TABLE 5.1-2. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 3 of 7)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| orbiter only: o Orbit navigation (I) | X | X | | | | | | | | X | |
| orbiter only: o Delta V thrust maneuvers (I) | X | X | | | | | | | | X | |
| orbiter only: o Stationkeeping (I) | X | X | | | | | | | | X | |
| orbiter only: o Orbital attitude maneuvers and control (V) | X | X | | | | | | | | X | |
| o Entry guidance and control (V) | X | X | | | | | | | | X | |
| o Aerodynamic attitude maneuvers and controls (H) | X | X | | | | | | | | X | |
| o Terminal approach and landing guidance (H) | X | X | | | | | | | | X | |
| o Rendezvous navigation (I) | X | X | | | | | | | | X | |
| o Aborts (I) | X | X | | | | | | | | X | |
| - Manual modes: via rotational side stick controller/translation controller/throttle controls/pedals | | | | | | | | | | | |
| o On-orbit delta V thrust maneuvers (I) | X | X | | | | | | | | X | |
| o Stationkeeping (I) | X | X | | | | | | | | X | |
| o Docking (I) | X | X | | | | | | | | X | |
| o Orbital attitude maneuvers and control-rate/proportional/ minimum impulse (V) | X | X | | | | | | | | X | |
| o Entry control (V) | X | X | | | | | | | | X | |
| o Aerodynamic attitude maneuvers and control (H) | X | X | | | | | | | | X | |

TABLE 5.1-2. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 4 of 7)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| o Terminal approach and landing (H) | X | X | | | | | | | | X | |
| o Roll-out guidance/braking (H) | X | X | | | | | | | | X | |
| o Go-around (H) | X | X | | | | | | | | X | |
| o Aborts (I) | X | X | | | | | | | | X | |
| ● Functional Requirements | | | | | | | | | | | |
| - Inertial reference unit - Capability of providing three axis ΔV's and attitude data (H) | X | X | | | X | X | | | | | |
| - Inertial reference unit - All attitude capability (H) | X | X | | | X | X | | | | | |
| - Optical tracker - Provide beacon angle track capability during rendezvous (I) | X | X | | | X | X | | | | | |
| - Optical tracker/horizon scanner - Provide horizon track during orbit navigation (V) | X | X | | | X | X | | | | | |
| - Optical tracker - Provide star track capability for IMU alignment (V) | X | X | | | X | X | | | | | |
| - Air data sensor - Provide static pressure, dynamic pressure, and temperature information (H) | X | X | | | X | X | | | | | |
| - Auxiliary rate sensors/accelerometers - Provide body rate/acceleration data (H) | X | X | | | X | X | | | | | |

TABLE 5.1-2. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 5 of 7)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analysis | Simulation | Similarity | Common Usage | Test | | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| | | | | | DVT | Qual | | | | | |
| - Crew flight controls - Provide manual control for: | | | | | | | | | | | |
| o Translation along 3 spacecraft axes (V) | X | X | | | X | X | | | | | |
| o Rotation about 3 spacecraft axes (H) | X | X | | | X | X | | | | | |
| o Thrust vector control (main) (H) | X | X | | | X | X | | | | | |
| o Turboject engine throttle control (H) | X | X | | | X | X | | | | | |
| o Runway steering and braking (H) | X | X | | | X | X | | | | | |
| o Final approach and landing (H) | X | X | | | X | X | | | | | |
| - Control electronics - Provide electronics for: | | | | | | | | | | | |
| o Main engine(s) control, throttling, and TVC (V) | X | X | | | X | X | | | | | |
| o ACPS control (V) | | | | | | | | | | | |
| o Elevon surface actuator control (H) | X | X | | | X | X | | | | | |
| o Rudder surface actuator control (H) | X | X | | | X | X | | | | | |
| o ABE throttle servos and control (H) | X | X | | | X | X | | | | | |
| o OMES control (I) | X | X | | | X | X | | | | | |

TABLE 5.1-2. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 6 of 7 )

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Performance Requirements | | | | | | | | | | | |
| - GN&C system shall achieve TPI at ± 10 min of preplanned time and ± 2 n mi rel altitude (I) | X | X | | | | | | | | X | |
| - GN&C system shall provide terminal rendezvous to within ± 500 feet of target (I) | X | X | | | | | | | | X | |
| - GN&C system shall achieve desired target reentry point to within 5 n mi (1 σ ) at Alt = 100 kft Vel = 1500 fps (V) | X | X | | | | | | | | X | |
| GN&C Software | | | | | | | | | | | |
| • Computational Requirements - GN&C Subsystem | | | | | | | | | | | |
| - Calculate guidance steering signals/engine discretes (V) | X | X | | | | | | | | X | |
| - Perform navigation calculations (V) | X | X | | | | | | | | X | |
| - Issue augmentation/calibration/ compensation signals (V) | X | X | | | | | | | | X | |
| - Positioning of navigation and rendezvous sensors (I) | X | X | | | | | | | | X | |
| - Issue GN&C S/S configuration/ moding commands (H) | X | X | | | | | | | | X | |
| - Supply GN&C data for controls and displays (H) | X | X | | | | | | | | X | |

TABLE 5.1-2. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 7 of 7)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| - Accept uplink information (V) | X | X | | | | | | | | X | |
| - Provide downlink information (V) | X | X | | | | | | | | X | |
| - Perform digital autopilot calculations (H) | X | X | | | | | | | | X | |
| - Accept and process crew commands (H) | X | X | | | | | | | | X | |
| - Perform guidance calculations (V) | X | X | | | | | | | | X | |
| - Pre-launch calibration - inertial equipment (V) | X | X | | | | | | | | X | |
| - Issue antenna pointing data to telecom S/S (V) | X | X | | | | | | | | X | |
| - Pre-launch alignment - inertial equipment (V) | X | X | | | | | | | | X | |
| • Interfaces | | | | | | | | | | | |
| - Verify GN&C subystem equipment functional interfaces with: | | | | | | | | | | | |
| o Data management system (H) | X | X | | | | | | | | X | X |
| o Controls and displays (H) | X | X | | | | | | | | X | X |
| o Telecommunications (H) | X | X | | | | | | | | X | X |
| o Power (H) | X | X | | | | | | | | X | X |

TABLE 5.1-3. GUIDANCE NAVIGATION AND CONTROL
REQUIRED EQUIVALENT UNITS

| Hardware Description | Required *Equiv. Units |
|---|---|
| Flight hardware per vehicle | 3 |
| Component devel & qual test | 2 1/2 |
| Integration tests | |
| • Full mission simulation lab | 1 |
| • Integrated avionics test lab | |
| • Flight controls hydraulic test lab | |
| • Mechanical systems test rigs | |
| • Propulsion fluid breadboards | |
| • Escape system test rig | |
| Test articles | |
| • Propulsion test article | .2 |
| • Structural test article | |
| Spares for flight test program | 1.3 |
| Spares for 445 flights | 3 |

*Basic non-redundant set

TABLE 5.1-4. GUIDANCE NAVIGATION AND CONTROL SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Operations - flight test support equipment - horiz/vert flight tests<br>- Automated telemetry station<br>o Digital computer facilities<br>o Displays<br>o Space/position trackers - FPS-16<br>o Theodolite facilities - incl acquisition radar<br>o Target aircraft with cooperative transponders<br>• GN&C integration test activity<br>- Flight attitude table<br>- Interface equipment - iron monster/GN&C equipment/FMES<br>- RF navigation aid simulators<br>- Cockpit mockup with integrated controls/displays/controllers<br>- Miscellaneous environmental/cooling equipment<br>- Test initiation/monitoring/control equipment<br>• IATS activity - Pre-vehicle installation testing<br>- GN&C equipment - BTME - for:<br>o Inertial measurement unit · Navigation aids<br>o Optical system · Autoland navigation equip.<br>o Control electronics · Air data sensor<br>· Rate sensors/accelerometers |
| Software | • Operations - flight test support<br>- Real-time and post-flight data handling<br>- Flight test parameter data extraction<br>• GN&C integration test activity<br>- Flight software package - mission simulation test software package<br>- GN&C equipment integration test software package |

TABLE 5.1-5. GUIDANCE NAVIGATION AND CONTROL
BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| • Four gimbaled inertial measurement unit | X | | | |
| • LM optical rendezvous system-mod | | | X | orbiter only |
| • Air data sensor | | X | | |
| • Auxiliary rate sensors and accelerometers | | X | | |
| • Aero surfaces control electronics | | X | | |
| - Elevon/rudder | | X | | |
| • ABE control electronics | | X | | |
| • OME control electronics | | | X | orbiter only |
| • Main engine control electronics | | X | | |
| • ACPS control electronics | | X | | |

TABLE 5.1-6. GUIDANCE NAVIGATION AND CONTROL FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Govt |
|---|---|---|---|---|
| GN&C hardware/software integration test facility (FMSL) | X | | X | |
| Integrated avionics test stand (all avionics subsystems) | X | | X | |

## 5.2 DATA MANAGEMENT SYSTEM

The data management system is responsible for the processing associated with:

- Guidance, navigation, and control functions
- Display and command functions
- Onboard checkout
- Redundancy management
- Onboard targeting and mission planning
- Data acquisition
- Sequencing and control

The principal elements of the data management system are:

- Digital computers
- Data buses
- Digital interface units
- Software

A block diagram of the computer complex configuration is seen in Fig. 5.2-1. It consists of two isolated computer complexes; namely, a data management computer complex (DMC) and a flight control computer complex (FCC). With this partitioning, rapid reconfiguration capability and higher order redundancy are provided where they are required without imposing these constraints on all functions.

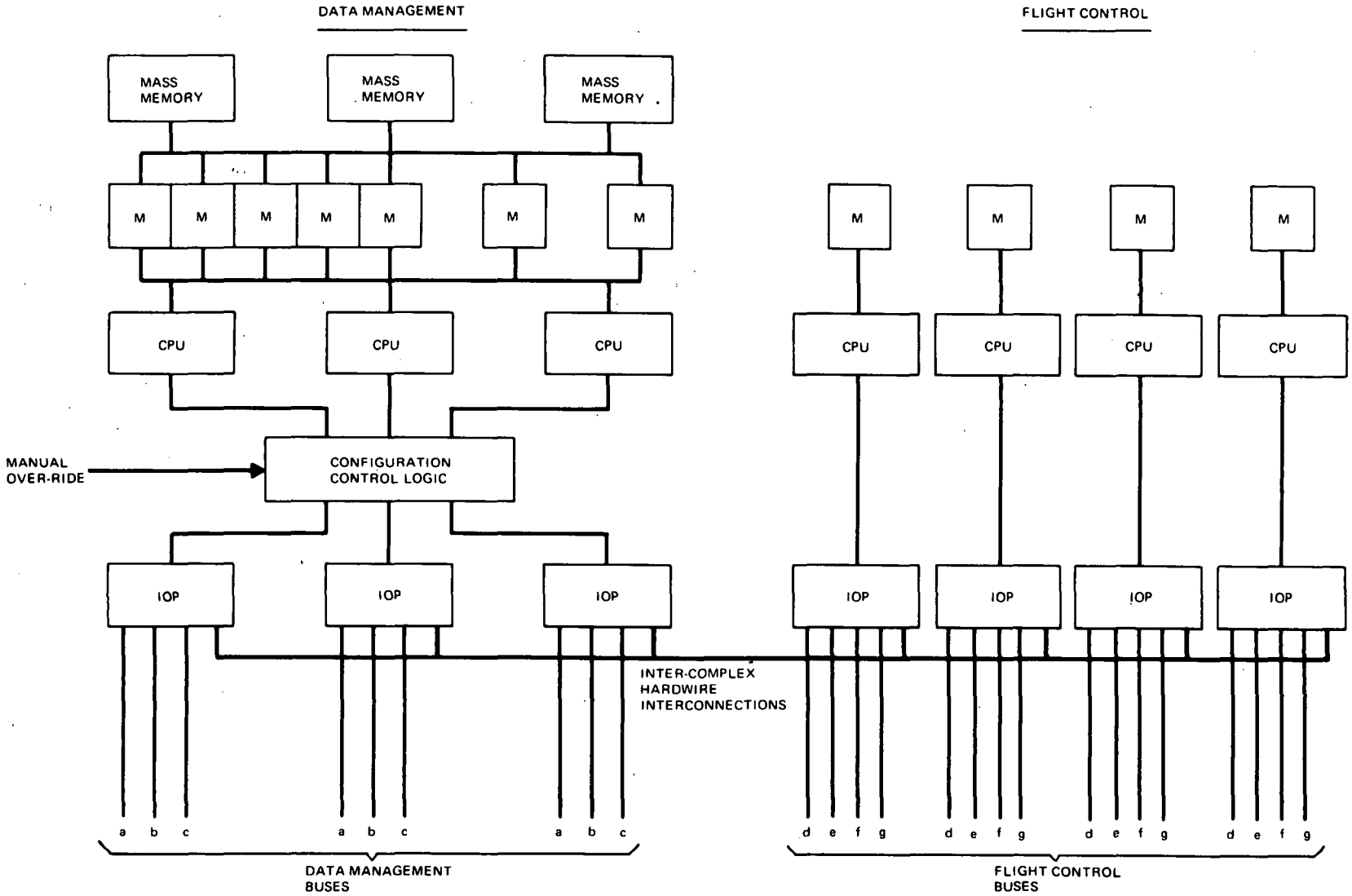



Fig. 5.2-1 Shuttle Computer Complex

The concept has two busing systems, one for each computer complex. The DMC system consists of triply redundant buses with twelve regional *RACUs, and the FCC system consists of quadruply redundant buses with sixteen regional RACUs. All buses are identical in terms of operation and implementation. The RACU subsystem interface portion can be expanded modularly to accommodate various interface requirements. The data bus interface portion is standard. The system is designed to accommodate as many as sixty-four RACUs; however, only twenty-eight are baselined.

Software reliability and software cost are of paramount importance in the space shuttle data management system. To reduce cost the following items are baselined:

- Use of floating point hardware
- Deliberate oversizing of mass memory, main fixed memory, and main working memory capacities
- Deliberate oversizing of computational, input/output and data bus throughputs
- Avoidance of external interrupts on a demand basis
- Avoidance of multiprocessor software

*Remote Acquisition and Command Unit

Software is the principal problem area in the data management system. The orbiter operational software must be compatible with the software of the booster, ground operations, main engines, and payloads. In addition, commonality in compilers, diagnostics/modules, etc, must be taken advantage of where practicable. The "software control board," a super-software group, is designed to ensure commonality and compatibility among the main program elements.

Aside from this interface with the software control board, the orbiter software development (OSDL) laboratory described in subsection 1.1.2 has a prime interface with subsystemvendors, IATL, flight test, man-machine simulation (FMSL), mission simulation (FMITF), and the iron bird (FCHTL). Coordination of these seven major interfaces in a timely fashion constitutes a major problem. In addition to the operational software for FMOF, we have special FLT test software requirements during each development mission and special checkout and build-up software for IATL.

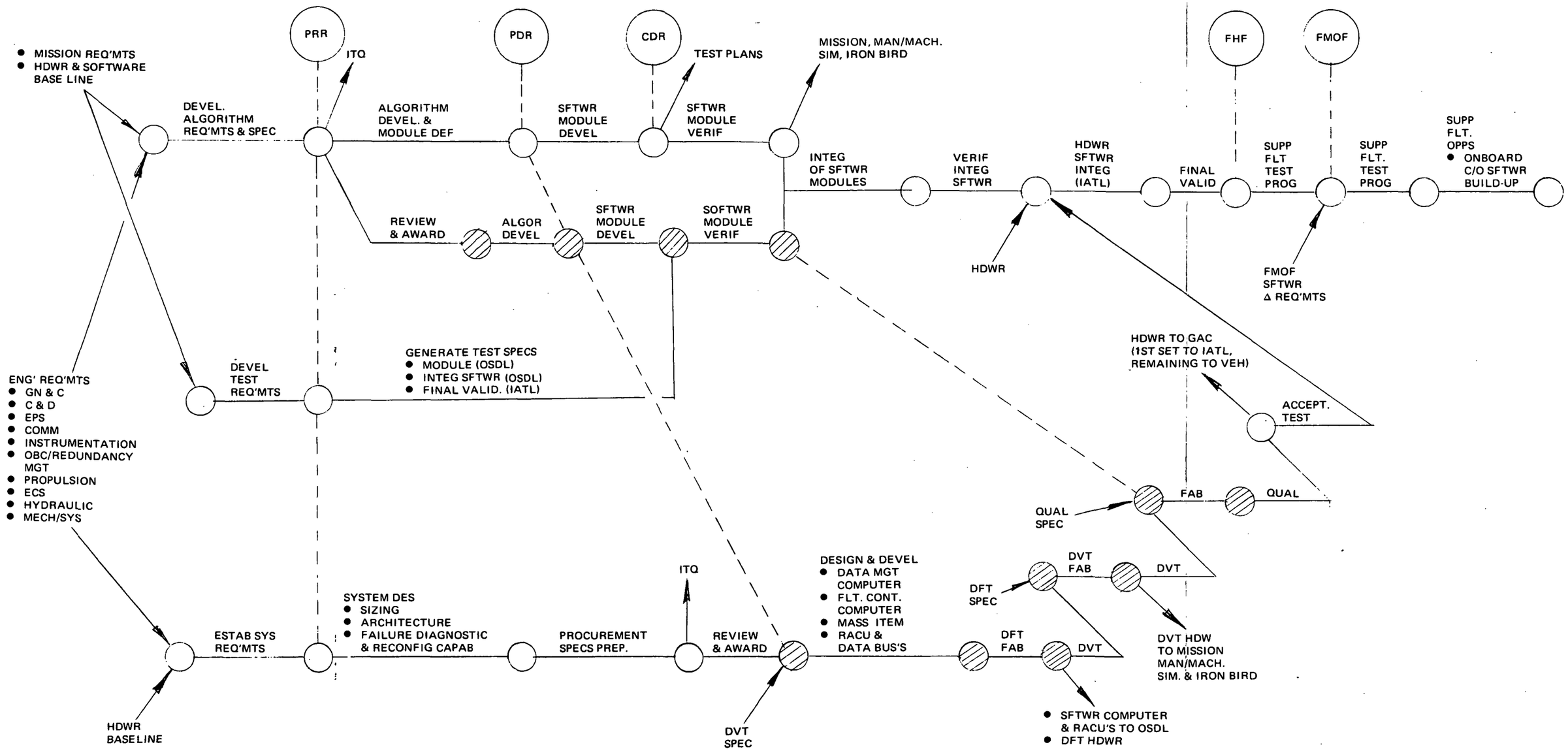



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Fig. 5.2-2 Data Management Logic Network



GRUMMAN
BOEING

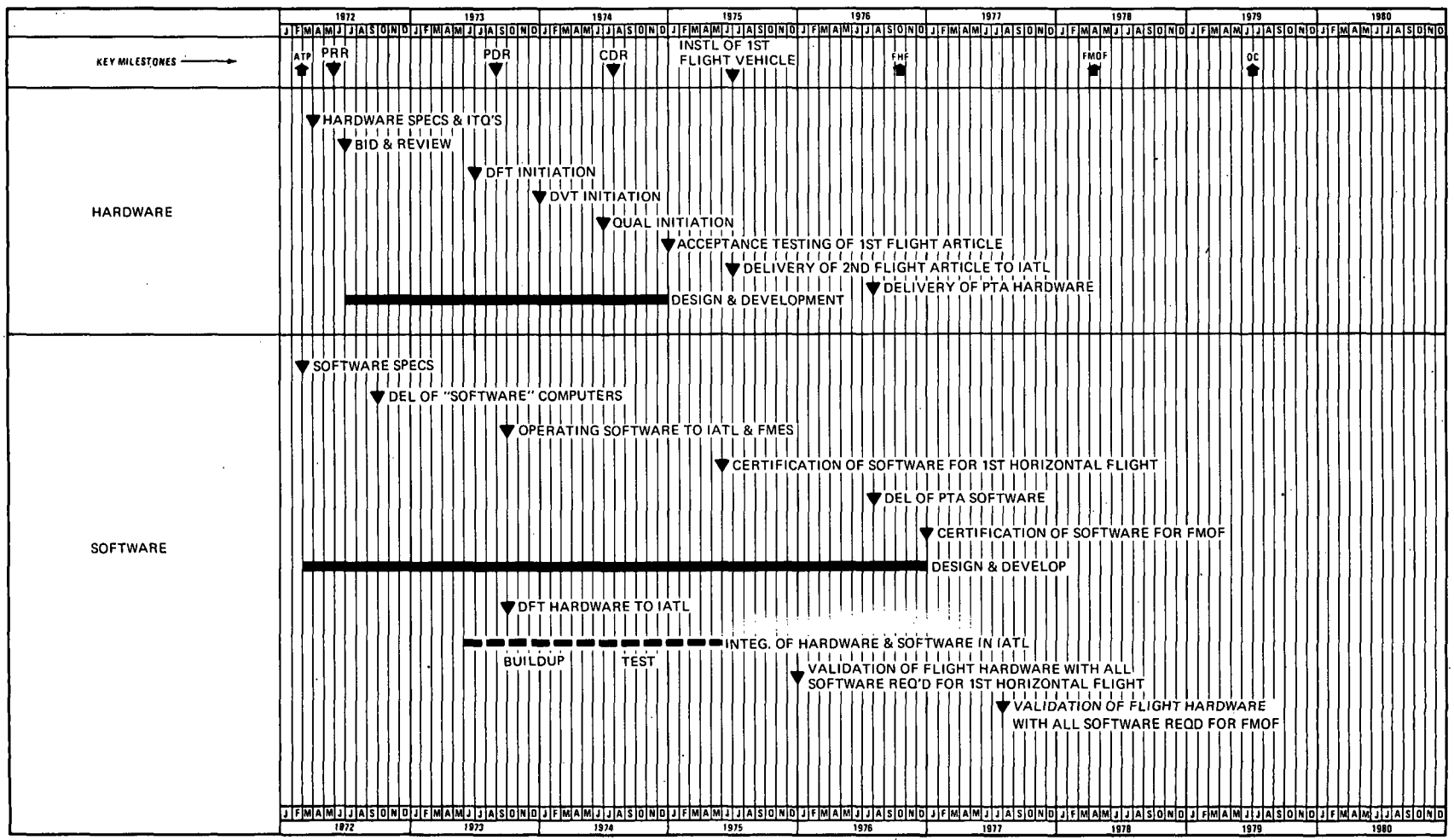


Fig. 5.2-3 Data Management Schedule

Verification of module and integrated software is done in the OSDL. Integration of hardware and software is done on the IATL, and validation of the flight software is done on FMITF. All testing, verification, validation, and changes must be coordinated through the software control board.

TABLE 5.2-1. SUBSYSTEM CERTIFICATION REQUIREMENTS

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Hardware feasibility | X | X | | | X | | | X | X | | |
| • Temperature, vibration, pressure, shock, acceleration, etc. | | | | | | X | | X | X | | |
| • "O" g qualification | | | | | | X | | | X | | |
| • Verify detection, isolation, and false alarm capabilities of OBC | X | X | | | X | | | X | X | | |
| • Verify functional and reliability effectiveness of software modules | | X | | | X | | | | | | |
| • Integrated hardware/software test | | X | | | | | | | | X | |
| • Verify reconfiguration capabilities | X | X | | | X | | | X | X | | |

TABLE 5.2-2. MAJOR COMPONENT LIST

| Comp. No. | Component Description | Qty/ Vehicle | Weight Each | Size Each | Power Each |
|---|---|---|---|---|---|
| | • DM/G&N Computer Complex | | | | |
| | - Mass memory | 3 | 15.0 | 175 | 20 |
| | - Main memory modules | 7 | 6.5 | 216 | 24 |
| | - CPU | 3 | 2.7 | 105 | 72 |
| | - I/O | 3 | 2.7 | 105 | 72 |
| | - Reconfiguration logic | 1 | 5.4 | 210 | 144 |
| | • Flight Control Computer Complex | | | | |
| | - Main memory modules | 4 | 6.5 | 216 | 24 |
| | - CPU | 4 | 2.7 | 105 | 72 |
| | - I/O | 4 | 2.7 | 105 | 72 |
| | • RACU | | | | |
| | - DM/G&N | 12 | 11.0 | 300 | 20 |
| | - FC | 16 | 11.0 | 300 | 20 |

TABLE 5.2-3. REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv Units |
|---|---|
| • Flight hardware per vehicle | 1 |
| • Component devel and qual test | 2-1/2 |
| • Integration tests | |
| - Full mission simulation lab | 2 |
| - Integrated avionics test lab | 1 |
| - Flight controls hydraulic test lab | |
| - Mechanical systems test rigs | |
| - Propulsion fluid breadboards | |
| - Escape system test rig | |
| • Test Articles | |
| - Propulsion test article | |
| - Structural test article | |
| • Spares for flight test program | 1.3 |
| • Spares for 445 flights | 6 |

TABLE 5.2-4. BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| • DM/computer complex | X | | | |
| • FC computer complex | X | | | |
| • Software | | | | Significant differences in GN&C software |
| • DM/G&N signal acquisition and distribution | X | | | |
| • FC signal acquisition and distribution | X | | | Increased number of main engines on booster might necessitate additional RACUs |

TABLE 5.2-5. FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Govt |
|---|---|---|---|---|
| • Software computer(s) (2 or 3 of each type) and peripherals | X | | | |
| • Laboratory floor space (3000 sq ft) | | X | | |
| • 12 benches (10 ft) | | X | | |
| • Development test equipment | X | X | | |
| - Scopes | | | | |
| - Pulse generator | | | | |
| - Voltmeters, ammeters | | | | |
| - Power supplies | | | | |
| - Test stands | | | | |
| - Paper tape recorders; tape & card punchers and readers | | | | |
| - Printers, consoles | | | | |
| • Special digital and analog test and simulation equipment | X | | | |
| • Environmental test laboratory | | X | | |

TABLE 5.2-6. SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Mass memory for re-loading FC program<br>• Carry-on stimulus equipment for pre-launch checkout<br>• Special test programs for subsystem pre-launch checkout<br>• Bench maintenance complex<br>- Memory exerciser<br>- General digital test console<br>- Tape drive<br>- Remote terminal for time-sharing to central mass memory |
| Software | • Subsystem diagnostics and test programs<br>• Mission and equipment simulation |

TABLE 5.2-7. SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Mass memory for re-loading FC program<br>• Special carry-on stimulus equipment for pre-launch checkout<br>• Special test programs for subsystem pre-launch checkout<br>• Bench maintenance complex<br>- Memory exerciser<br>- General digital test console<br>- Tape drives<br>- Remote terminal for time-sharing to central mass memory |
| Support Software | • Subsystem diagnostics and test programs, 300 K<br>• Mission and equipment simulation, 200 K (FMSL, FMITE) |
| Operational Software Requirements | • Guidance and navigation 16 K<br>• Sequencing and control 5 K<br>• Command and display proc 20 K<br>• Flight control 8 K<br>• OBC, redundancy and SS management 35 K<br>• Mission planning 6 K<br>• Executives and utility programs compilers as required 10 K |

# 5.3 INSTRUMENTATION

## 5.3.1 OPERATIONAL INSTRUMENTATION

Operational instrumentation will provide sufficient measurement points on the orbiter for the collection of data used in the assessment of subsystem performance, and onboard checkout information, during pre-launch and flight periods for the operations phase. Typical measurement will include temperature, frequency, voltage, pressure, valve/switch position, quantity gauging. Where required, physical data will be converted to a uniform voltage format (nominally 0-5V) through the application of transducer/sensors environmentally and structurally compatible with the measurement media. Material compatibility experience from the Apollo program will be used as a guide in transducer selection.

As illustrated in the simplified block diagram shown in Fig. 5.3.1-1 all measurements will either be routed to a remote acquisition and control unit (RACU) for processing and transmission to a data buss system or hardwired directly to displays or data recorders. The use of a data buss system greatly reduces the complexity of operational instrumentation since it eliminates the need for a dedicated multiplexer. The RACU's receive measurements directly and eliminate the need for long hardwire runs.

Rigorous ground rules such as fault propagation prevention, hardware subassembly replacement level, signal and power ground isolation have extraordinary leverage on instrumentation cost reduction and trouble-free operation, and will therefore be established at the outset of Phase C/D. The operational instrumentation on the Apollo LM applied these rules successfully to produce a relatively simple and reliable system. Similar rigor will be applied to the orbiter. For simplification of data processing all new sensors will be bought or designed to the same normalized linear output characteristics (integral signal conditioning). All measurements from subsystems will be required to have the same output characteristics to appropriately interface with the RACU. Exception to this rule may be equipment bought "off-the-shelf." Availability and low cost of off-the-shelf equipment may justify the use of separate conditioning equipment. Separate signal conditioner packages located remotely from the sensor may also be required if it is not possible to use solid-state

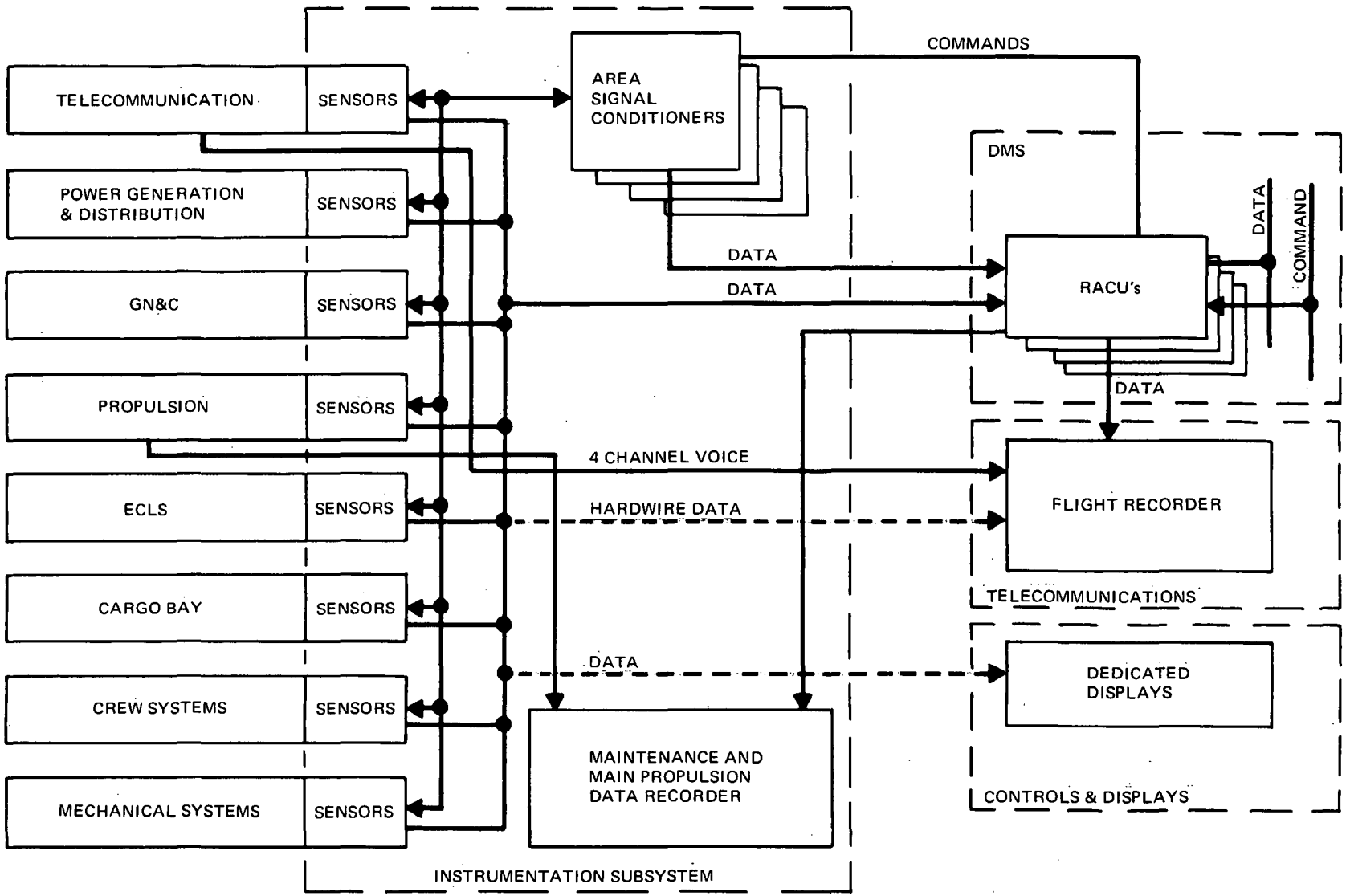


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Fig. 5.3.1-1 Instrumentation Subsystem Block Diagram

electrical components in the local measurement area because of severe local environments (engine high temperature, reentry temperature, etc). Other than these two general exceptions the objective will be to keep separate signal conditioning to a minimum. The number of measurements on the orbiter will exceed that of Apollo spacecraft primarily because of the increased requirements of onboard checkout. Experience has shown that active management of the measurement list can maintain both the number and accuracy of measurements within reasonable bounds by deletion of "nice-to-have" requests. The total number of orbiter operational measurements is now estimated at 3000. Approximately one third of this total is estimated to be discrete type which are easily handled with negligible impact on the data management system.

It is expected that a high percentage of orbiter measurements can be made with previously qualified "off-the-shelf" measuring devices. However, some unusual applications are expected and alternates must be explored before any new sensor design is undertaken.

In past space programs, indirect measurement and computation has been effective in eliminating the need for complex special-purpose designs. On the Apollo program pressure and temperature measurements have been used effectively in the computation of gaseous quantity in zero g, thus eliminating the need for special equipment designs. Examples are the LM ascent and descent propulsion helium and gaseous oxygen tanks wherein the requirements were adequately met using these techniques. Less straightforward examples which might, in retrospect, have been handled the same way include the RCS propellant quantity measuring device which started out as a complex nucleonic gaging system. Fairly early in the program a PT integrated measuring device (PQMD) was substituted and successfully developed. It has turned out to be a criticality 9 item (not critical for mission success) and therefore, a standard pressure sensor would now suffice. A similar decrease in requirements has been experienced on the water quantity measurement device (WQMD), thus permitting the economical resolution of a compatibility problem which turned up after the unit was in production.

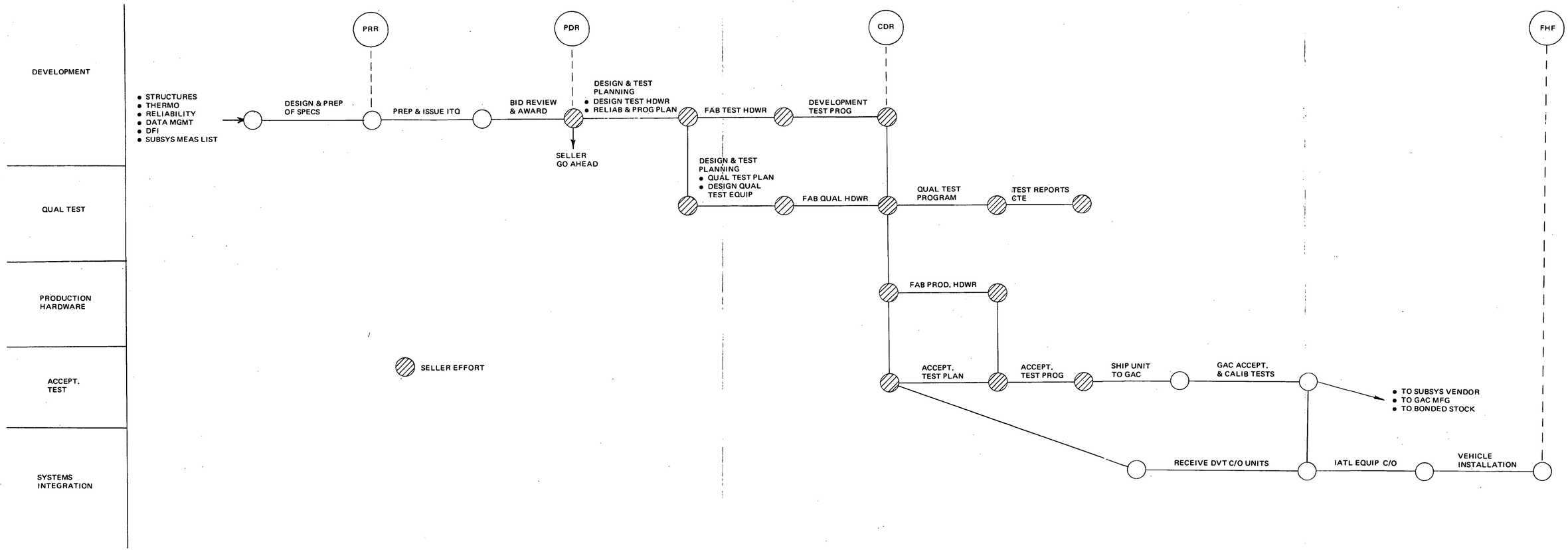


Fig. 5.3.1-2 Operational Instrumentation Logic Network

WBS NO. 01030300

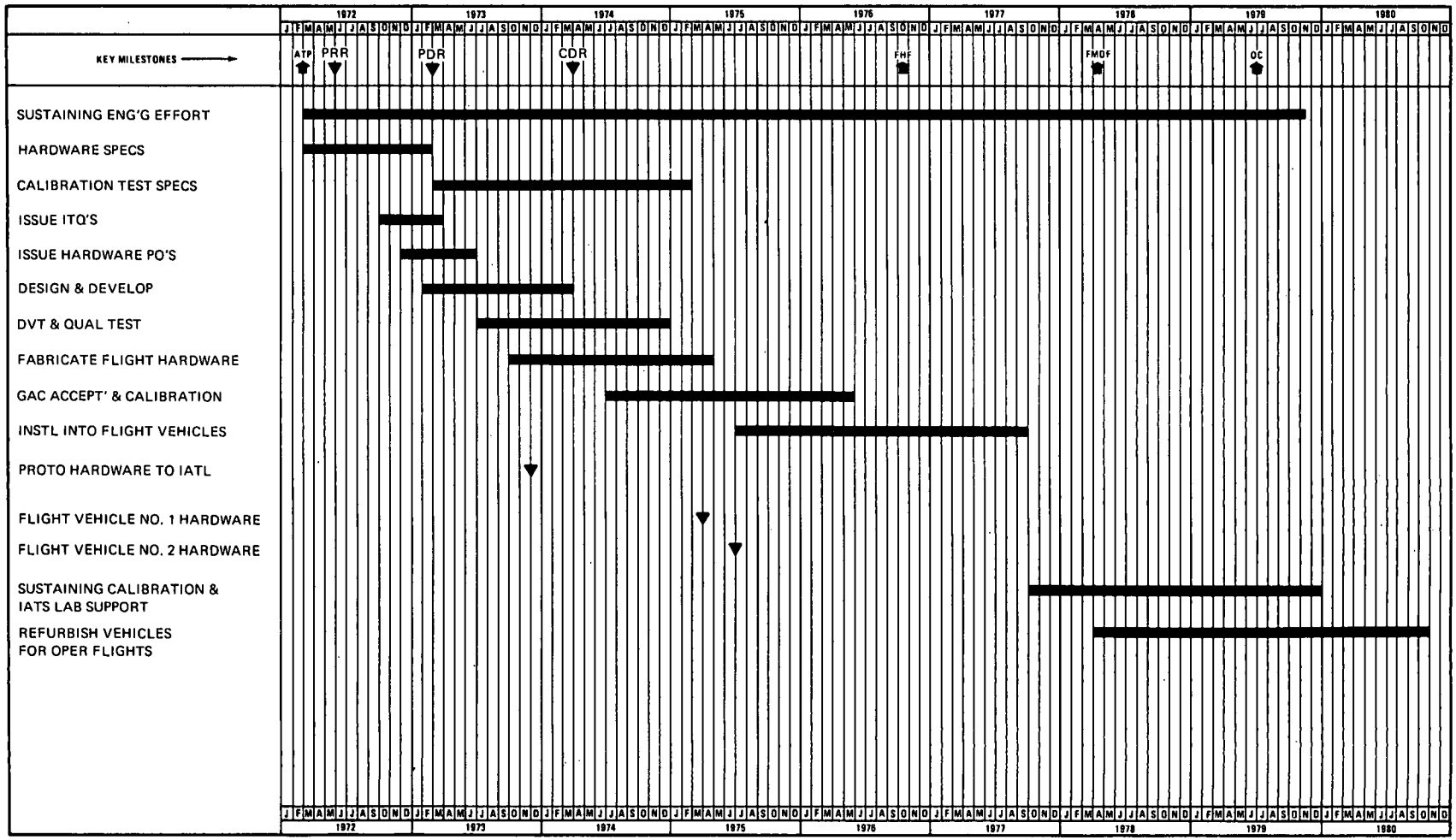








Fig. 5.3.1-3 Avionics Operational Instrumentation Schedule

On the orbiter the extent to which simple systems can be implemented will be determined by the stringency to which the initial measurement requirements are specified.

The selected baseline "H" system greatly simplifies fluids instrumentation by requiring only high and low point sensors in the injection tanks (for loading and depletion) and capacitance gaging in the OMS tank.

This area will require contained close attention during the C/D Phase in the interest of both cost and development risk avoidance.

TABLE 5.3.1-1 CERTIFICATION REQUIREMENTS

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Anaylsis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Sensor and Transducers | | | | | | X | X | | | | |
| Signal Conditioners | | | | | | X | | X | | | |
| Maintenance & Main Propulsion Data Recorder | | | | | | X | | X | | | |

TABLE 5.3.1-2 MAJOR COMPONENT LIST

| Component Description | Qty/ Vehicle | Weight Each, lb | Size Each, in | Power Each, watt |
|---|---|---|---|---|
| • Sensors* | | | | |
| - Pressure (High Level) | 150 | .5 | 1.5 | 1.25 |
| - Pressure (Low Level) | 250 | .1 | .5 | .02 |
| - Temperature | 600 | .1 | .2 | .001 |
| - Flow | 80 | .75 | 2.0 | - |
| - Quantity | 20 | 2.5 | 1.0 | 4.0 |
| - RPM | 80 | .1 | .5 | - |
| - Discrete | 1200 | .02 | .2 | - |
| - Current | 100 | .5 | 2.0 | 1.0 |
| - Specials Measurement Sensors | 150 | .5 | 2.0 | 3 |
| • Signal Conditioner | 20 | 5 | 38.4 | 10 |
| • Maintenance & Main Propulsion Data Recorder | 1 | 150 | 6000 | 600 |

*Note: All discrete measurements and approximately 40% of analog measurement to be integrated into subsystems. The weight of these sensors are accounted for in the weight of the subsystems.

TABLE 5.3.1-3. SUBSYSTEM CERTIFICATION REQUIREMENTS

| Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Sensor and Transducers | | | | | | X | X | | | | |
| • Signal Conditioners | | | | | | X | X | | | | |
| • Maintenance & Main Propulsion Data Recorder | | | | | | X | X | | | | |

TABLE 5.3.1-4. REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv Units |
|---|---|
| • Flight Hardware per Vehicle | 1* |
| • Component Devel & Qual Test | 2-1/2 |
| • Integration Tests | |
| - Full Mission Simulation Lab | |
| - Integrated Avionics Test Lab | 1/2 |
| - Flight Controls Hydraulic Test Lab | |
| - Mechanical Systems Test Rigs | |
| - Propulsion Fluid Breadboards | |
| - Escape System Test Rig | |
| • Test Articles | |
| - Propulsion Test Article | |
| - Structural Test Article | |
| • Spares for Flight Test Program | 1-1/2 |
| • Spares for 445 Flights | 6 |

* 1 Unit consists of 1 complete ship set of hardware

TABLE 5.3.1-5. SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| • Support Equipment | None Required |
| • Software | |
| | |

TABLE 5.3.1-6. BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| • Sensors | | | | |
| - Pressure | X | | | |
| - Temperature | X | | | |
| - Flow | | X | | |
| - Quantity | | X | | |
| - RPM | X | | | |
| - Discrete | X | | | |
| - Current | X | | | |
| - Specials Measurement Sensors | | | X | |
| • Signal Conditioner | | X | | |
| • Maintenance & Main Propulsion Data Recorder | | X | | |
| • Measurements List - Computer Program | X | | | |



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TABLE 5.3.1-7. FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr. | Govt |
|---|---|---|---|---|
| • Acceptance Test and Calibration | | X | X | X |
| • Hardware Storage 300 sq ft | | X | | X |
| • IATL Test Area: | | | | |
| - Testing (TBD) | | X | | X |
| • Flight Test Area | | | | |
| - Calibration Area | | X | | X |
| - Hardware Storage | | X | | X |

TABLE 5.3.1-8. COMPUTER SUPPORT REQUIREMENTS

Computer support is required for:

I. Maintenance of Operational Instrumentation Measurements Lists

II. Measurement Equipment Configuration List

III. Hardware Status Lists

IV. Calibration Data

The Operational Measurement List is an up-to-date listing by subsystem of the measurements required and characteristics of these measurements with respect to sampling rate, accuracy, resolution and termination requirements. The Measurement Equipment Configuration List is an up-to-date record of the sensor, signal conditioning and recording equipment required to implement the instrumentation function. The Hardware Status List gives the status of each procured hardware item with respect to development, qualification, vendor, delivery and in-house location. The Calibration Data Program is a listing of sensor raw data and the computational algorithms required to perform sensor calibration.

These programs will be executed on the IBM 360/75 computer.

## 5.3.2 DEVELOPMENT FLIGHT INSTRUMENTATION (DFI)

Two outstanding program characteristics will greatly influence the design of the development flight instrumentation (DFI) system; the large quantity of data to be gathered and the limited number of test vehicles available. Other areas of concern will be the effective use of test time and the DFI/data reduction interface.

### 5.3.2.1 Limited Number of Test Vehicles

Since only two test vehicles will be available, it will be necessary for each to have backup capability for the other, allowing either to take over the other's test role if necessary.

### 5.3.2.2 Large Quantity of Data

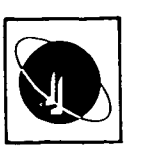
To obtain the maximum amount of information from each flight with minimum DFI hardware, operational instrumentation will be used where possible. It may prove cost effective to accept a small operational instrumentation size and reconfiguration penalty in order to effect a major reduction in DFI hardware. In general only those measurements that have high frequency response requirements or are beyond the capacity of the operational instrumentation are candidates for DFI. Nevertheless, it is probable that the large quantity of data needed, in conjunction with the limited number of available test vehicles, will require the following DFI system characteristics:

- Multiple telemetry links configured for wide band transmission
- Large data channel capacity
- Inflight data format modification using stored program techniques
- Sophisticated data acquisition equipment

This system is depicted schematically in Fig. 5.3.2-1.







5.3.2.3 Effective Use of Test Time

Effective use of test time will be obtained through:

- Extensive preliminary preparation through the use of the "IATL." The entire data acquisition system will be integrated with the avionics system prior to installation in the vehicle
- Application of proven techniques and equipment previously developed for and used in the F-111B, EA-6B, E-2C, and F-14 flight test programs

5.3.2.4 DFI/Data Reduction Interface

It will be a DFI design goal to interface with the selected data reduction facility with minimum requirement for modification to that existing facility.

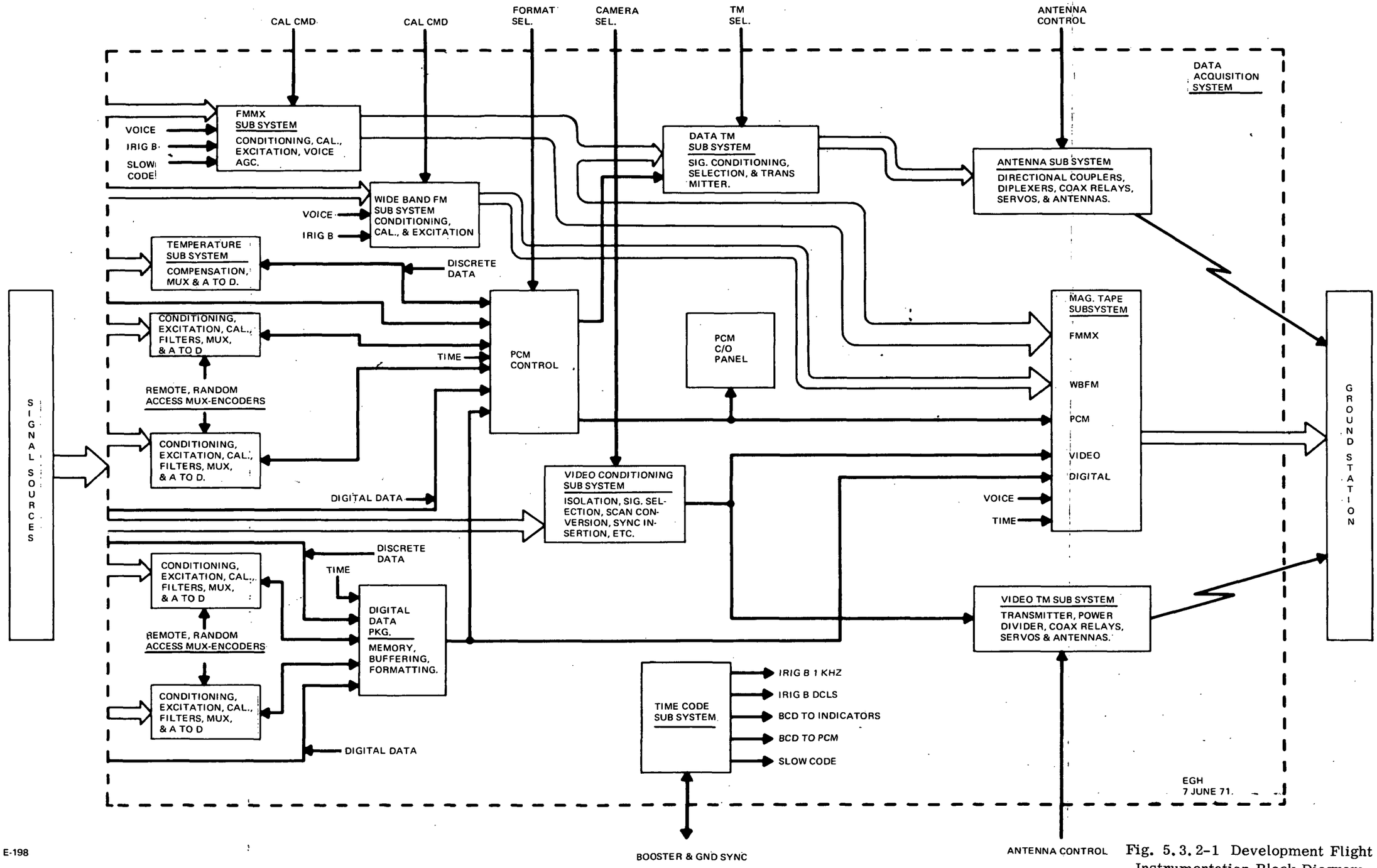



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Fig. 5.3.2-1 Development Flight Instrumentation Block Diagram

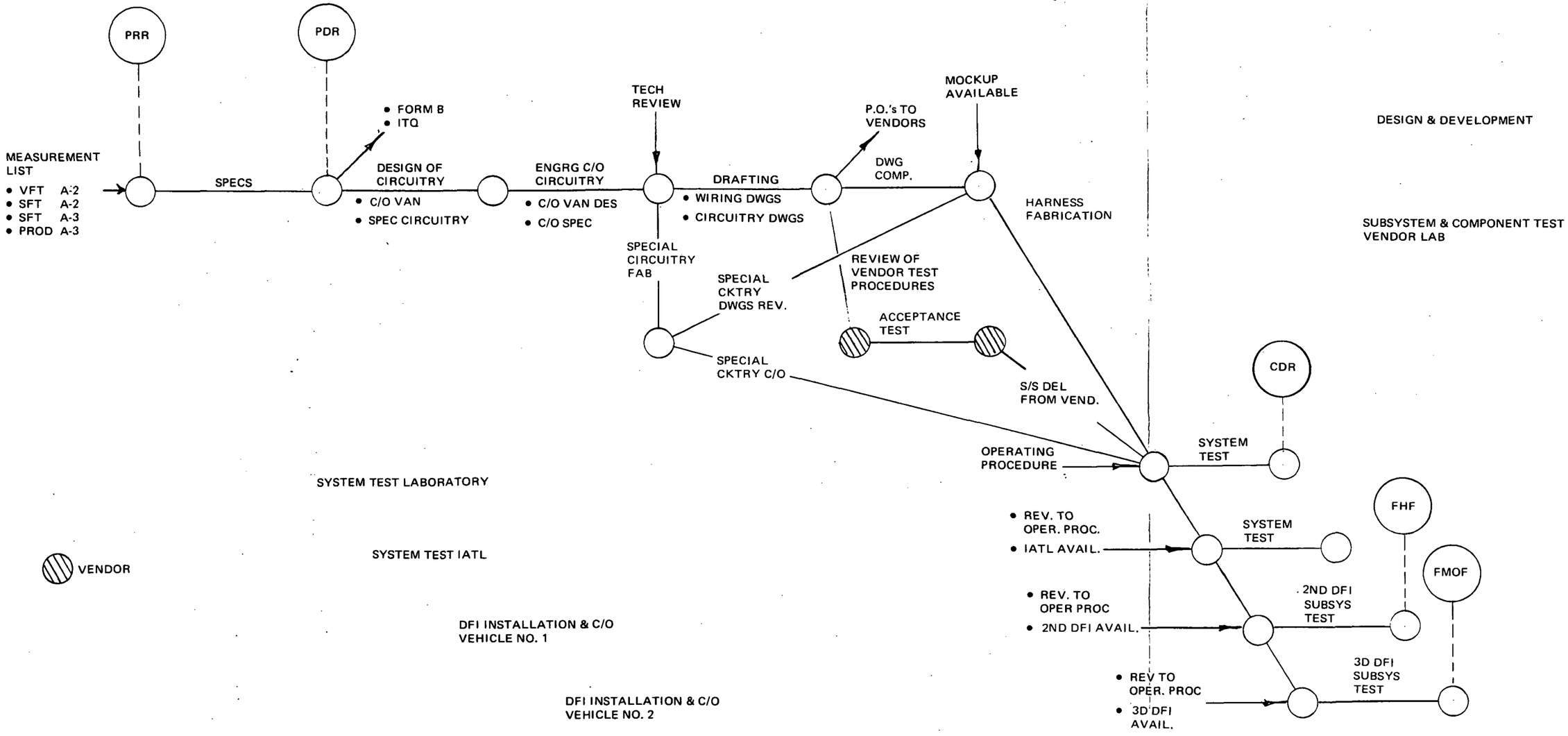


Fig. 5.3.2-2 Development Flight Instrumentation Logic



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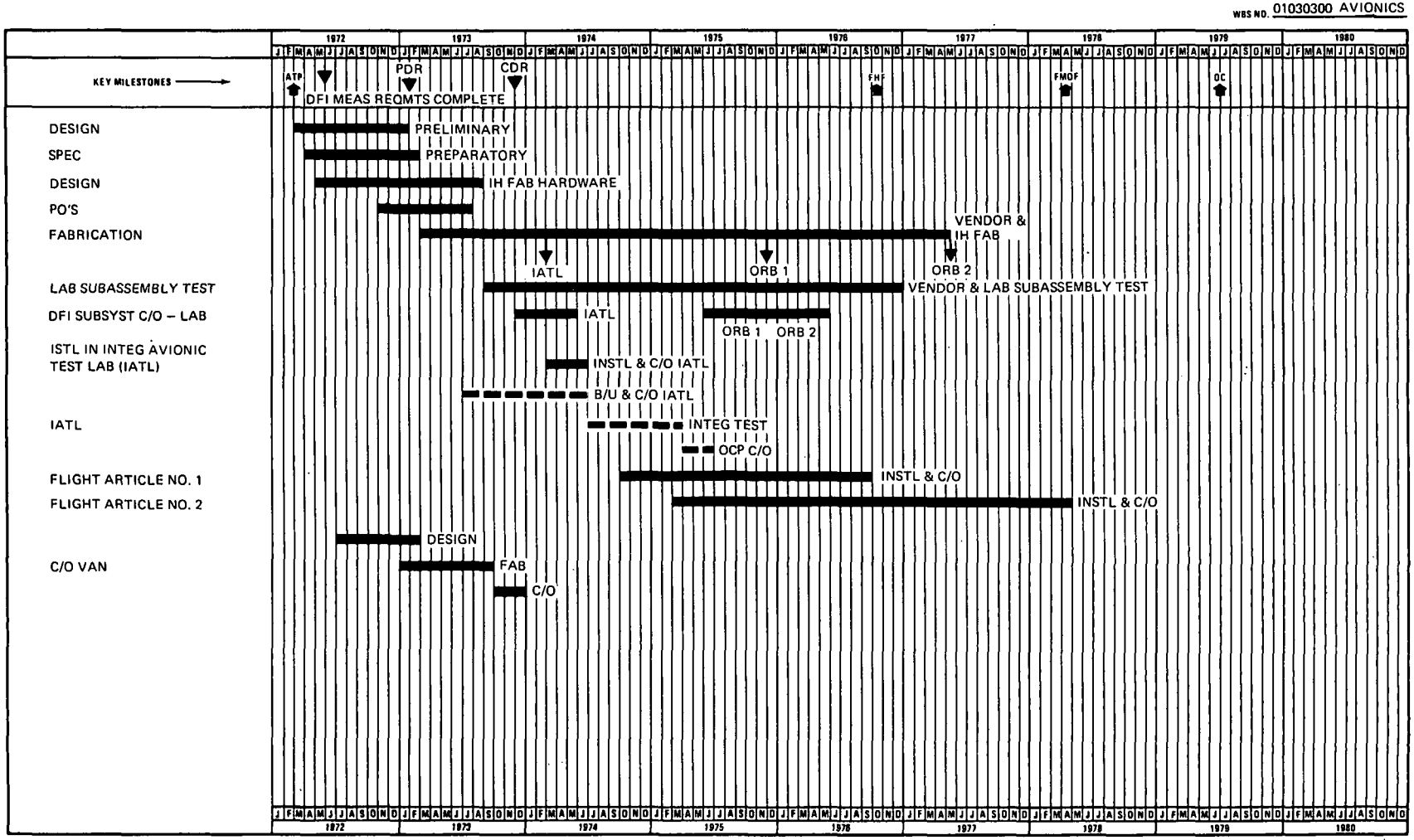


Fig. 5.3.2-3 Development Flight Instrumentation Schedule

TABLE 5.3.2-1. SUBSYSTEM CERTIFICATION REQUIREMENTS

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| FMMX Subassembly | | | | | | X | | X | | | |
| Temperature Subassembly | | | | | | X | | X | | | |
| WBFM Subassembly | | | | | | X | | X | | | |
| PCM Subassembly | | | | | | X | | X | | | |
| Digital Data Package | | | | | | X | | X | | | |
| Time Code Subassembly | | | | | | X | | X | | | |
| Data Telemetry Subassembly | | | | | | X | | X | | | |
| Antenna Subassembly | | | | | | X | | X | | | |
| Video Conditioning Subassembly | | | | | | X | | X | | | |
| Video Telemetry Subassembly | | | | | | X | | X | | | |
| Magnetic Tape Subassembly | | | | | | X | | X | | | |
| Checkout Van | | | | X | | | | X | | | |

TABLE 5.3.2-2. MAJOR COMPONENT LIST

| Comp. No. | Component Description | Qty/Vehicle | Weight, lb | Size, cu ft | Power, watts |
|---|---|---|---|---|---|
| 1 | FMMX Subassembly | 1 | 88 | 2 | 214 |
| 2 | Temperature Subassembly | 1 | 200 | 13 | 2390 |
| 3 | WBFM Subassembly | 1 | 28 | 0.7 | 67 |
| 4 | PCM Subassembly | 1 | 1896 | 36.9 | 2828 |
| 5 | Digital Data Package | 1 | To Be Determined | | |
| 6 | Time Code Subassembly | 1 | 20 | 1.0 | 80 |
| 7 | Data TM Subassembly | 1 | 125 | 3.3 | 1541 |
| 8 | Antenna Subassembly | 1 | To Be Determined | | |
| 9 | Video Conditioning Subassembly | 1 | To Be Determined | | |
| 10 | Video TM Subassembly | 1 | To Be Determined | | |
| 11 | Magnetic Tape Subassembly | 1 | 339 | 10.1 | 1010 |
| 12 | Checkout Van | 1 | N/A | N/A | N/A |

TABLE 5.3.2-3. REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv. Units |
|---|---|
| Flight Hardware Per Vehicle* | 1 |
| Component Devel & Qual Test | |
| Integration Tests | |
| • Full Mission Simulation Lab | |
| • Integrated Avionics Test Lab | 1 |
| • Flight Controls Hydraulic Test Lab | |
| • Mechanical Systems Test Rigs | |
| • Propulsion Fluid Breadboards | |
| • Escape System Test Rig | |
| Test Articles | |
| • Propulsion Test Article | |
| • Structural Test Article | |
| Spares For Flight Test Program | 1/2 |
| Spares For 445 Flights | |
| *One Equivalent Unit Required Per Test Vehicle | |

TABLE 5.3.2-4. FACILITY REQUIREMENTS LIST

| Development Phase | Lab Floor Space, sq ft | Power | New | Exist. | Contr. | Govt |
|---|---|---|---|---|---|---|
| Design | 1000 | Negligible | | X | X | |
| Lab Checkout | 2000 | 115/208, 400 Hz, 25A.<br>115/208, 60 Hz, 50A.<br>28 VDC Variable @ 200A. Max. | | X | X | |
| IATL Checkout | 400 at IATL | Same | X | | | X |
| | 400 Adj. To IATL | | X | | | X |
| | 900 Lab C/O Area | | | X | X | |
| Orbiter Checkout | 400 Adj. To Orbiter | Same | X | | | X |
| | 900 In Lab C/O Area | | | X | X | |
| Shuttle Checkout | 400 Adj. To Shuttle | Same | X | | | X |
| | 900 In Lab C/O Area | | | X | X | |

In addition, the assumption is made that the DFI C/O van and a normal amount of electronic lab equipment is available.



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TABLE 5.3.2-5. BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Signal Sources | | X | | Scheduling and backup capability require one ship set per vehicle. However, commonality will yield savings in one time engineering charges and spares inventory. |
| FMMX Subassembly | | X | | |
| Temperature Subassembly | | X | | |
| WBFM Subassembly | | | | |
| PCM Subassembly | | X | | |
| Digital Data Package | | X | | |
| Time Code Subassembly | | X | | |
| Data TM Subassembly | | X | | |
| Antenna Subassembly | | X | | |
| Video Conditioning Subassy | | X | | |
| Video TM Subassembly | | X | | |
| Mag. Tape Subassembly | | X | | |
| Checkout Van | | X | | |

TABLE 5.3.2-6. COMPUTER SUPPORT REQUIREMENTS

1. Measurement list software development.
2. Analysis of input capabilities and limitations of the selected data reduction facility.

TABLE 5.3.2-7. SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Miscellaneous Electronic Lab Equipment<br>• Calibration Equipment<br>• DFI Checkout Van |
| Software | • Data reduction programs to utilize inflight calibration signals |

## 5.4 TELECOMMUNICATIONS AND AIR TRAFFIC CONTROL SUBSYSTEM

### 5.4.1 SUBSYSTEM DESCRIPTION

The shuttle telecommunications and air traffic control subsystem, hereafter called the communications subsystem, provides the capability for internal voice, external voice, and data communications, and augments the onboard guidance and navigation subsystem with rf navigation, rendezvous, and landing aids. A communications subsystem block diagram is shown in Fig. 5.4-1, and the major component list is contained in Table 5.4-2. The primary features of the subsystem are:

- Communications
  - Unified S-band (USB) communications between the orbiter and MSFN stations, space station, and launch control, providing two-way, duplex voice and data transmission
  - VHF communications between the orbiter and ground via TDRS, providing two-way, duplex voice or data transmission
  - S-band communications between the orbiter and booster while mated, providing two-way, duplex voice and data transmission
  - VHF communications between the orbiter and air traffic control stations, providing two-way simplex voice
  - S-band command data link between the orbiter and external tanks
  - Internal voice communications via audio centers and modulator/demodulator (modem) between crew and passengers and external rf links
  - Survivable-type voice and data recorder and VHF radio beacon

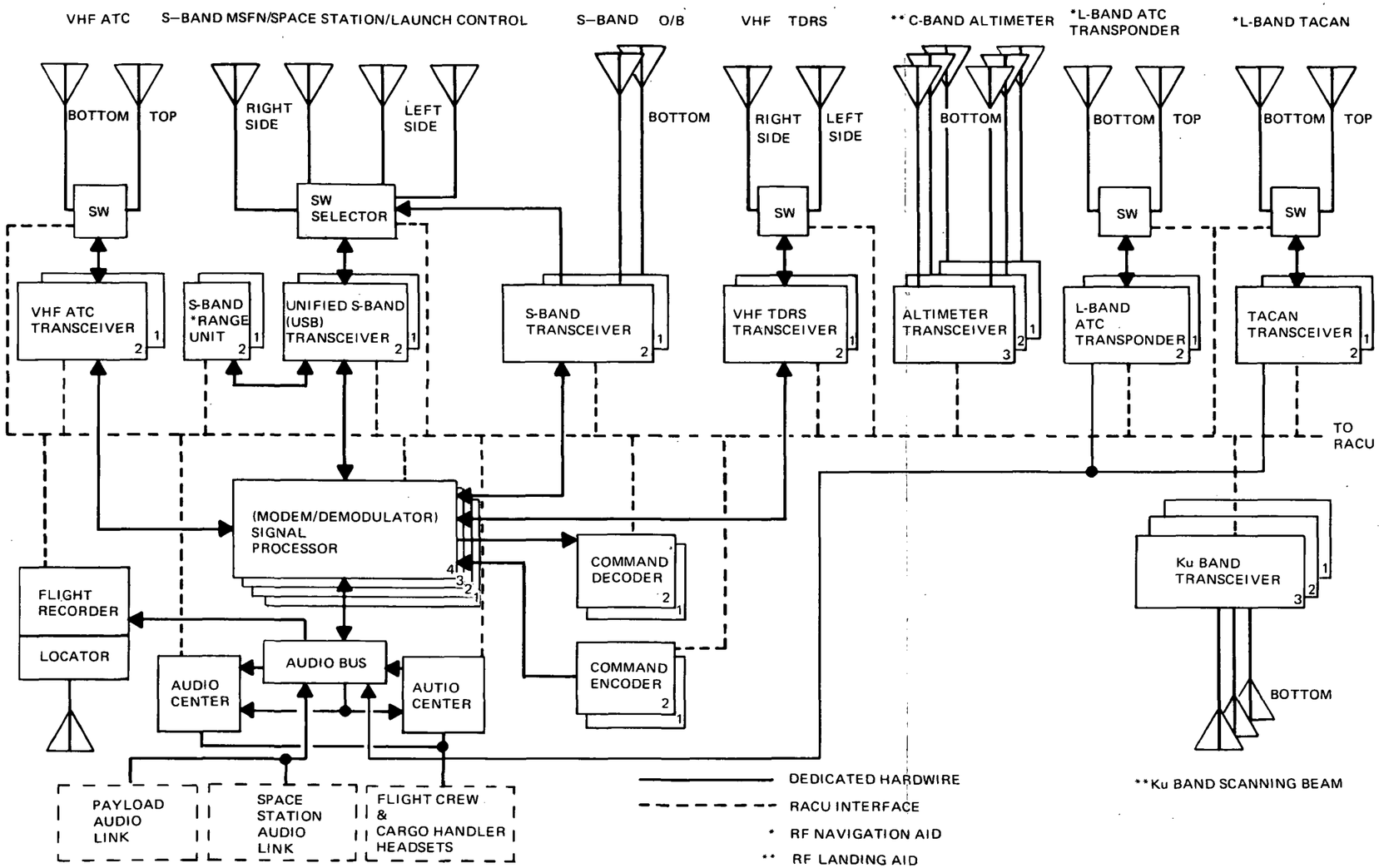




Fig. 5.4-1 Communications Subsystem Block Diagram



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- RF navigation and landing aids
  - USB communications provides turnaround PRN ranging signals for state vector update
  - L-band TACAN provides the orbiter with bearing and distance measurement to a ground station for state vector update
  - C-band altimeter provides the orbiter with altitude measurement during approach and landing
  - Ku-band scanning beam (MSB) system provides the orbiter with range, azimuth, and elevation information to support an automatic landing
  - VHF communications via TDRS provides turnaround ranging for state vector update
  - Ranging unit via USB communications provides capability to rendezvous with cooperative target (space station)
  - L-band transponder provides vehicle identification and altitude information to FAA air traffic control stations

The approach used in the development of the communications subsystem is presented in the logic and constraint network and bar schedule shown in Fig. 5.4-2 and 5.4-3, respectively. Two separate parallel development activities are identified, one related to antennas (developed and manufactured at Grumman) and the other for procured components (i.e., transmitters, receivers, etc.). In general, the subsystem is synthesized from a mix of off-the-shelf (e.g., TACAN, ATC transponder) and new development hardware (e.g., antennas, signal processor). Off-the-shelf equipment will be modified as a result of delta qualification tests wherever necessary.

## 5.4.2 DEVELOPMENT ISSUES

Significant technical development areas of the communications subsystem are:

- Antennas and radomes that survive the high temperature re-entry and are reusable
- RF landing aid capability for automatic vehicle landing

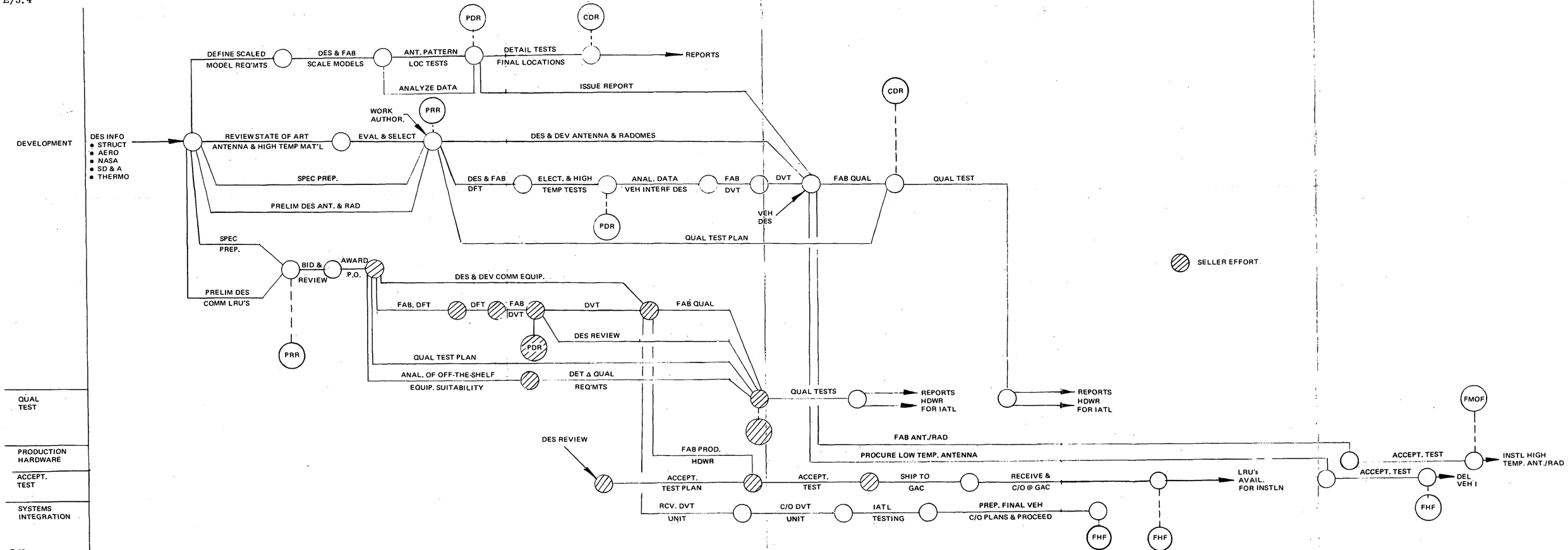


Fig. 5.4-2 Orbiter Communications Subsystem Logic Network

WBS NO. 01030400

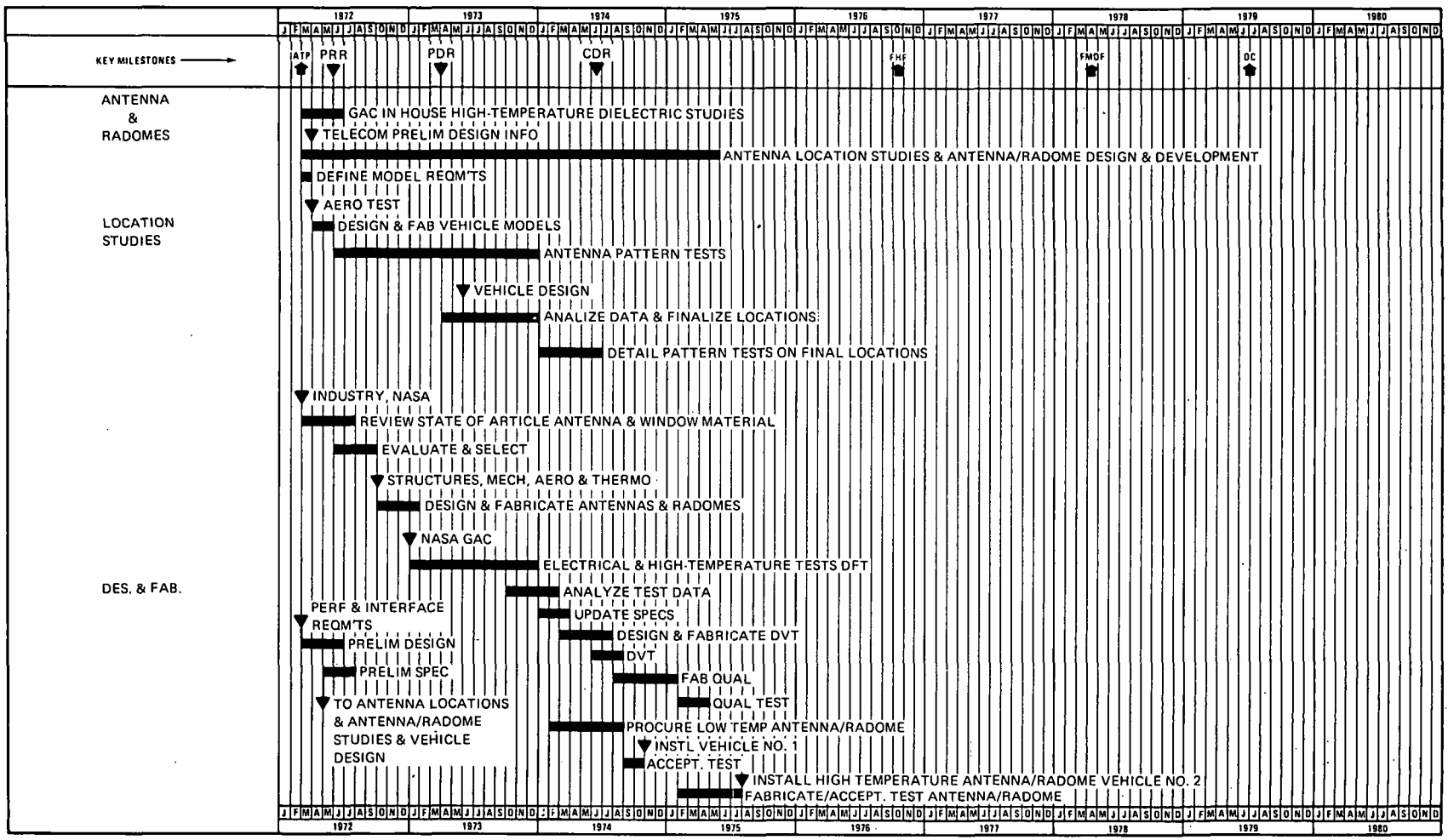


Fig. 5.4-3 Communications Subsystem Schedule (Sheet 1 of 2)

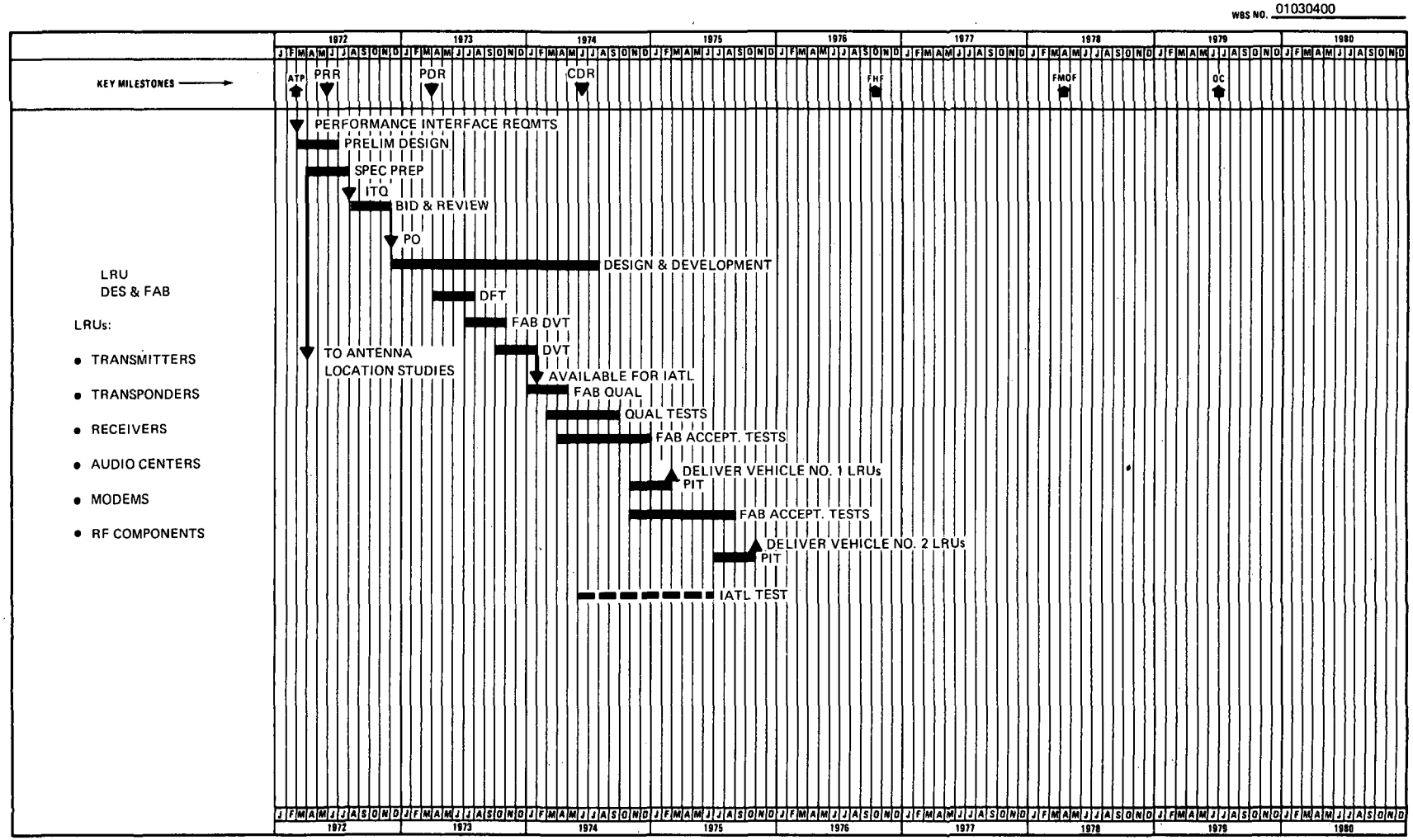


Fig. 5.4-3 Communications Subsystem Schedule (Sheet 2 of 2)

- Subsystem checkout, sequencing, and reconfiguration when interfaced with the data management and displays and controls subsystems

Proven development methods and techniques, demonstrated by the multitude of successful state-of-the-art antenna and radome components configured for aircraft and spacecraft, provide Grumman with the unique experience and tools necessary to effectively meet the demands of the shuttle antenna and radome complement. Notable examples are the high temperature CSM transponder radome, high temperature/high power jammer system antenna and radome components for Navy aircraft, and the lightweight, rugged VHF and S-band antennas for LM.

Figure 5.4-3 emphasizes the importance Grumman places on establishing a firm technical foundation prior to freezing the shuttle high temperature antenna and radome designs. Current in-house high temperature TPS dielectric material studies will be expanded to include fabrication and test of candidate flush-mounted antenna and radome designs. This comprehensive approach will provide timely design of the critical vehicle interface and will enable first vertical flight with fully qualified antennas and radomes.

Since the orbiter will have an automatic landing capability, an rf landing aid integrated to perform with the G&N subsystem, will require special attention. The baseline microwave scanning beam (MSB) technology has been developed by the military, and tested by the FAA. Recommendations by the Radio Technical Committee for Aeronautics (RTCA) Special Committee 117 may necessitate modifications to the existing MSB technology. Parallel consideration of the precision ranging system (PRS) as a alternate is warranted to provide the automatic landing capability and assist in navigation and rendezvous.

Grumman is currently conducting a System 621B user equipment definition and experiment program under contract with the Air Force, in which one phase will be devoted to the performance capability of automatic landings in a multipath environment. Studies to integrate an all weather terrain following radar sensor with the automatic flight control system in the Grumman A-6A aircraft has been accomplished and recommended to the Navy. These programs, along with Grumman's accrued experience with automatic carrier landing systems (ASW-25, ASW-27, ARA-63) for high performance Navy aircraft, will enable the implementation of the rf landing aid for the shuttle in sufficient time for the first horizontal flight.

Subsystem checkout, sequencing, and reconfiguration are essential in the operation of the integrated avionics system. Communications subsystem checkout experience on Navy/Grumman aircraft (E-2C, EA-6B, F-14A) programs demonstrated that early identification of checkout requirements and interfaces to the onboard computer subsystem is necessary to ensure successful operational capability. Further, detailed testing in the SITS facilities of the EA-6B and F-14A allowed early verification of the communications subsystem interfaces and checkout procedures. Communication subsystem integration into the shuttle avionics system will be demonstrated in the IATL facility utilizing the experience gained on these current Grumman aircraft programs. This approach will allow sufficient time to "feedback" any fixes in the fabrication of hardware for the flight vehicles.

### 5.4.3 CERTIFICATION PLAN

The communications subsystem certification requirements are enumerated in Table 5.4-1. They are divided according to the method of certification and level of assembly. Further, the number of required equivalent units, booster/orbiter commonality candidates, support requirements, facility requirements, and computer support requirements are described in Tables 5.4-3 through 5.4-7.

TABLE 5.4-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 5)

| LEGEND: H = Constraint on first Horizontal flight; V = Constraint on FMOF; I = Constraint on IOC<br>Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Operational Requirements | | | | | | | | | | | |
| H - Compatibility with existing ground MSFN and ATC facilities to minimize RFI | X | | | | X | | | | X | | X |
| V - Verify communications subsystem redundancy management and OBC capability while under control of the onboard computer, RACU, and D&C | X | | | | X | | | | | X | X |
| H - Evaluate communications subsystem susceptability to EMI and monitor EMI generation | X | | | | X | | | X | | X | X |
| H - Capability of communications subsystem to meet operational requirements during horizontal flight test | X | | | | X | | | | | | X |
| V - Capability of communications subsystem to meet operational requirements during vertical flight test | X | | | | X | | | | | | X |
| V - Capability of communications subsystem to operate within performance limits under environments specified | | | | | | X | | | | | X |
| • Navigation and Landing Aids Requirements | | | | | | | | | | | |
| H - VHF locator performance capability | | | | | X | | | | X | | X |

TABLE 5.4-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 5)

| LEGEND: H = Constraint on first horizontal flight; V = Constraint on FMOF; I = Constraint on IOC<br>Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| V - Ranging unit performance capability | X | | | | X | | | | | X | |
| H - Radio altimeter performance capability | X | | | | X | | | | | X | |
| H - Capability of ATC transponder to respond to ground interrogation | X | | | | | | | | X | | X |
| H - Capability of TACAN to interrogate transponder stations and interface with DMS to provide navigation updates | X | X | | | X | | | | | X | X |
| H - Capability of MSB to interface with ground station and DMS to provide automatic landing functions | X | X | | | X | | | | | X | X |
| • RF Systems Requirements | | | | | | | | | | | |
| V - Adequate antenna radiation coverage by antennas for all RF links in the mated and unmated configurations on an antenna range | X | X | | | | | X | | | | |
| H - Compatibility of antennas with applicable transmitters, receivers, and antenna selectors | | | | | X | X | | | | | X |
| V - Capability of antenna selectors to be operated by the DMS or manually | | | | | X | X | | | | X | X |

TABLE 5.4-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 5)

| LEGEND: H = Constraint on first horizontal flight; V = Constraint on FMOF; I = Constraint on IOC<br>Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| H - Proper transceiver operation with low/high power | | | | | X | X | | | | | X |
| H - Modem signal processors provide proper interface between rf equipments, audio centers, and DMS | X | | | | X | | | | X | X | |
| H - RF equipments accomplish proper signal modulation and demodulation | | | | | X | | | | X | | |
| V - Proper operation of all antenna systems in the shuttle thermal environment when integrated in TPS | | X | | | | X | | | | | X |
| H - Capability of rf equipment operation with antennas and cables to verify ERP levels, modulation efficiencies, insertion losses, VSWR, and heat dissipation | X | | | | X | | | | | | X |
| V - Selected rf equipments are not degraded by corona effects while operating in a vacuum | | | | | | X | | X | | | |
| H - Evaluate rf systems for EMC requirements to ensure no radiation or absorbed radiation from other rf sinks/sources | X | | | | | | | | X | | X |

TABLE 5.4-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 4 of 5)

| LEGEND: H = Constraint on first horizontal flight; V = Constraint on FMOF; I = Constraint on IOC<br>Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Computer and Displays and Controls Requirements | | | | | | | | | | | |
| V - Capability to transfer digital data between orbiter and booster via rf data link | | | | | X | | | | X | | X |
| V - Capability of RACU to communicate with communication subsystem LRU's and computer via data bus | | | | | X | | | | X | X | |
| V - Capability for manual selection of transceivers, modes, antennas | | | | | X | | | | | | X |
| H - Proper recording of data parameters via flight recorder | | | | | X | | | | X | X | |
| • Audio Systems Requirements | | | | | | | | | | | |
| H - Two-way simplex voice with ATC via vhf | | | | | X | | | | X | | X |
| H - Proper crew member, passenger intercommunications | | | | | X | | | | X | | X |
| V - Proper recording of voice via flight recorder | | | | | X | | | X | | | |
| H - Audio center-signal amplification, switching, and routing to audio bus and the vhf, S-band transceivers via the modem signal processor | | | | | X | | | X | | | |

TABLE 5.4-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 5 of 5)

| LEGEND: H = Constraint on first horizontal flight; V = Constraint on FMOF; I = Constraint on IOC<br>Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| V - Proper audio intercommunications through the rf O/B transceiver | | | | | X | | | | X | | X |
| H - Modem signal processor operation to verify signal modulation, demodulation, mixing, routing, and switching | | | | | X | | | | X | | |
| • Installation Checkout Requirements | | | | | | | | | | | |
| H - VSWR measurement of antennas with their coaxial cables and antenna selectors | | | | | X | | | | | | X |
| H - VSWR measurement in transmitters | | | | | X | | | | | | X |
| H - Verify receiver reception of transmitted signal | | | | | | | | | | | |
| H - Verify communications subsystem integration with DMS and OBC | | | | | X | | | | | | X |
| H - Verify coaxial cables do not radiate or absorb radiation from other rf sources | | | | | X | | | | | | X |
| H - Verify communications subsystem equipments do not radiate or absorb from other rf sinks/sources | | | | | X | | | | | | X |

TABLE 5.4-2 COMMUNICATIONS MAJOR COMPONENT LIST
(Sheet 1 of 2)

| Component Description | Qty/Veh | Weight Each (lb) | Size Each ($in.^3$) | Power Each (watts) |
|---|---|---|---|---|
| • Communications | | | | |
| - VHF TDRS xcvr | 2 | 50 | 1000 | 330 |
| - VHF TDRS antenna | 2 | 20 | TBD | - |
| - VHF TDRS ant. sel | 1 | 1 | 27 | 0.5 |
| - S-band USB xcvr | 2 | 21 | 686 | 40 |
| - S-band antenna | 4 | 5 | 125 | - |
| - S-band ant. sel | 1 | 2 | 54 | 2 |
| - VHF ATC xcvr | 2 | 29 | 1580 | 120 |
| - VHF ATC antenna | 2 | 20 | 7776 | - |
| - VHF ATC ant. sel | 1 | 1 | 27 | 0.5 |
| - Audio center | 2 | 5 | 100 | 10 |
| - Flight recorder/locator/antenna | 1 | 22 | 2880 | 21 |
| - O/B xcvr | 2 | 4 | 100 | 3 |
| - O/B antenna | 2 | 5 | 125 | - |
| - Modem signal processor | 4 | 7 | 160 | 15 |
| - Command decoder | 2 | 13 | 553 | 15 |
| - Command encoder | 2 | 5 | TBD | TBD |

TABLE 5.4-2 COMMUNICATIONS MAJOR COMPONENT LIST
(Sheet 2 of 2)

| Component Description | Qty/Veh | Weight Each (lb) | Size Each (in.$^3$) | Power Each (watts) |
|---|---|---|---|---|
| • RF navigation and landing aids | | | | |
| - Ku-band (MSB) xcvr | 3 | 25 | 344 | 60 |
| - Ku-band (MSB) antenna | 3 | 1 | 24 | - |
| - C-band altimeter | 3 | 7 | 86 | 45 |
| - C-band antenna | 6 | 4 | 100 | - |
| - L-band TACAN xcvr | 2 | 40 | 1500 | 207 |
| - TACAN antenna | 2 | 5 | 190 | - |
| - TACAN ant. sel | 1 | 1 | 27 | 0.5 |
| - L-band ATC xpndr | 2 | 27 | 200 | 10 |
| - ATC xpndr antenna | 2 | 5 | 190 | - |
| - ATC xpndr ant. sel | 1 | 2 | 27 | 3.5 |
| - Ranging unit | 2 | 5 | 200 | 10 |



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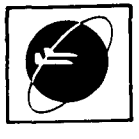

TABLE 5.4-3 REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv Units |
|---|---|
| • Flight hardware per vehicle | 1 |
| • Component devel and qual test | 2 |
| • Integration tests | |
| - Full mission simulation lab | .3 |
| - Integrated avionics test lab | 1 |
| - Flight controls hydraulic test lab | |
| - Mechanical systems test rigs | |
| - Propulsion fluid breadboards | |
| - Escape system test rig | |
| • Test articles | |
| - Propulsion test article | |
| - Structural test article | .1 |
| • Spares for flight test program | 1.25 |
| • Spares for 445 flights | 3 |

TABLE 5.4-4 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| VHF TDRS Xcvr | | | X | |
| VHF TDRS Antenna System | | | X | |
| S-band USB Xcvr | | | X | |
| S-band Antenna System | | | X | |
| S-band Ranging Unit | | | X | RF nav aid |
| VHF ATC Xcvr | X | | | |
| VHF ATC Antenna System | | X | | |
| Audio Center | X | | | |
| Flight Recorder/Locator | X | | | |
| O/B Xcvr | X | | | |
| O/B Antenna System | | X | | |
| Ku-band Xcvr | | X | | RF landing aid |
| Ku-band Antenna System | | X | | RF landing aid |
| C-band Altimeter | X | | | RF landing aid |
| C-band Antenna System | | X | | RF landing aid |
| L-band ATC Xpndr | X | | | RF nav aid |
| L-band ATC Antenna System | | X | | RF nav aid |
| Modem Signal Processor | X | | | |
| L-band TACAN | X | | | RF nav aid |
| L-band TACAN Antenna System | | X | | RF nav aid |
| Common Decoder | X | | | |
| Command Encoder | | | X | |





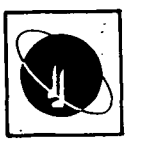

TABLE 5.4-5 SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Communication subsystem test control console<br>• RF ground station<br>• Specialized test equipment for navigation and landing aid equipment<br>• RF checkout equipment<br>• VSWR measurement unit<br>• Voice and data stimuli equipment<br>• Environmental test equipment<br>• EMI test equipment<br>• Electrical cable set<br>• Electrical ground power and distribution<br>• Automatic circuit analyzer<br>• Antenna pattern model test equipment |
| Software | • Software to implement the following:<br>- Control of test sequence<br>- Data acquisition and analysis<br>- Simulation of computer control and displays & control functions<br>- Documentation of test results |

TABLE 5.4-6 FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Gov |
|---|---|---|---|---|
| • Electronic systems center, Grumman Plant 14 antenna test facility | | X | | |
| • NASA high temperature antenna test facility | | | | X |
| • Screen room for EMI evaluation of LRU's | | X | | |

TABLE 5.4-7 COMPUTER SUPPORT REQUIREMENTS

| | | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Keypunch* (total hours per year) | | 210 | 210 | 120 | 120 | 120 | 20 | 20 | | | | | | | | | | 820 |
| Machine Time Estimate | 360-75 | 7 | 9 | 6 | 6 | 4 | 1 | 1 | | | | | | | | | | 34 |
| | 360-67 | 2 | | | | | | | | | | | | | | | | 2 |
| hour/yr | 360-30 | 7 | 10 | 5 | 4 | 2 | | | | | | | | | | | | 28 |
| Programming Estimate (hrs/yr) | | 1000 | 700 | 640 | 400 | 300 | 100 | 40 | | | | | | | | | | 3180 |

- Assumes use of existing program, Deck No. 50040, and a new communications link and multipath propagation program
- Antenna pattern model studies require computer analysis to calculate pattern coverage vs gain level and signal polarization. Existing programs will be modified
- Radome electrical characteristic of various material types will be analyzed. Existing program will be modified

* Assume 50 cards per hour

# 5.5 DISPLAYS AND CONTROLS SUBSYSTEM

## 5.5.1 FUNCTIONAL DESCRIPTION

The baseline displays and controls sybsystem is shown in Fig. 5.5-1. Principal features and design characteristics of the baseline include: Operation of the vehicle by a two-man flight crew; operation of the vehicle by one crewman under emergency conditions to effect a safe return; autonomous onboard and unambiguous operation, configuration control, and checkout of all subsystems; automatic or manual flight control for all mission phases; malfunction alerting and fault isolation as provided by each subsystem; places the crew in the role of decision maker; minimizes the use of dedicated instruments and toggle switches; and provides operational FO/ FO/FS redundancy for flight critical functions.

### 5.5.1.1 Multipurpose Display Set

A major portion of all the information presented to the crew will be via 4 multi-purpose, multi-format CRT displays. These displays will be mission-sequenced to provide the crew with the data required for a particular mission phase. Override features are built in to allow manual call-up of display parameters by the crew and automatic display of abort warning and OBC/C&W information by the data management system. Each display, when selected, has the capability of providing integrated prime flight data (e.g., vertical and horizontal situation, and energy management), sequential display of mission event checklists, OBC data, qualitative and quantitative display of subsystem status, external sensor information, data communications, and television.

### 5.5.1.2 Display Processor/Formatter

Redundant electronics providing buffer storage for incoming data, and refresh and formatting of information presented on the multi-purpose display set.

### 5.5.1.3 Microfilm Display and Electronics

Features manual or automatic selection of navigation charts, area approach maps, star charts, mission profile data, crew timelines, checklists, vehicle address codes, startup/shutdown procedures, and caution and warning malfunction procedures.

5.5.1.4 Data Entry/Display Keyboard and Processor Assemblies

The majority of all input commands to the vehicle system are made via the data management system utilizing these keyboard display assemblies. Each data entry and readout assembly enables the crew to enter and compute guidance and control parameters, initiate automatic checkout of the vehicle, initiate event sequences, control and obtain vehicle system status, and perform system tests. Computer-aided data entry/display techniques are utilized in conjunction with the data management system to eliminate the need for the numerous codes and manuals normally required to enter and call up data.

5.5.1.5 Caution and Warning Displays

Caution and warning annunciators are used to alert the crew to all vehicle anomalies or malfunctions. A tone system and two master reset pushbuttons are provided. Pushing the reset button acknowledges the alert and places information concerning the failure on one of the multipurpose displays in front of the crewman responding to the alert. Malfunctions requiring corrective action by the crew will force-drive the microfilm display to the appropriate data frame detailing the corrective action. The annunciators provide the primary crew alert during the periods when the multipurpose display set is shut down.

5.5.1.6 Subsystem Keyboards

Function keyboards are utilized to override computer-controlled functions where critical response is required by the crew or where such devices enhance crew efficiency (i.e., display moding, sequence initiation, subsystem control, etc.).

5.5.1.7 Dedicated Display and Control Devices

Dedicated display and control devices are used where usage rate precludes sharing, where immediate crew activation is required, or where necessary for vehicle initialization. The functions provided by these devices are hardwired if not required to interface with the DMS complex.

Note: Pilot flight control devices are covered under flight controls - subsection 3.5. Computer software requirements are covered in subsection 1.12.

5.5.1.8 Approach and Rationale

The development risk associated with the selected baseline approach is considered minimal. Equipments are modifications of existing designs or expansions thereof. The

proposed multipurpose CRT displays are similar to those developed for the Grumman A-6 series aircraft flying since 1962, the F-111, the F-14, and the Boeing SST. The proposed data entry/display keyboards are similar to those used on the Grumman E-2C aircraft for which many software routines exist. Experience derived during the development of these hardware systems provides confidence and assurance that the space shuttle design and development objectives can be achieved.

A systemized approach is used to develop the displays and controls subsystem, which includes the following: analysis of mission, vehicle, subsystem, crew, hardware, and lighting requirements; crew station mock-up studies and human factor evaluation of candidate designs; the development and evaluation of CRT display formats early in the program utilizing an interactive computer graphics terminal; a simulation program designed to evaluate D&C implementation concepts, display formats, software and crew proficiency; and a phased integration of D&C equipments into "IATL".

The DVT program is instituted with step-stress testing to reduce the risk of program constraining failures during equipment qualification. Certification of D&C hardware is accomplished at both the component and assembly level. D&C subsystem components and assemblies are subjected to both environmental and functional acceptance test procedures. Vehicle level OCP's and a flight test program are conducted to provide added confidence that all design objectives have been achieved.

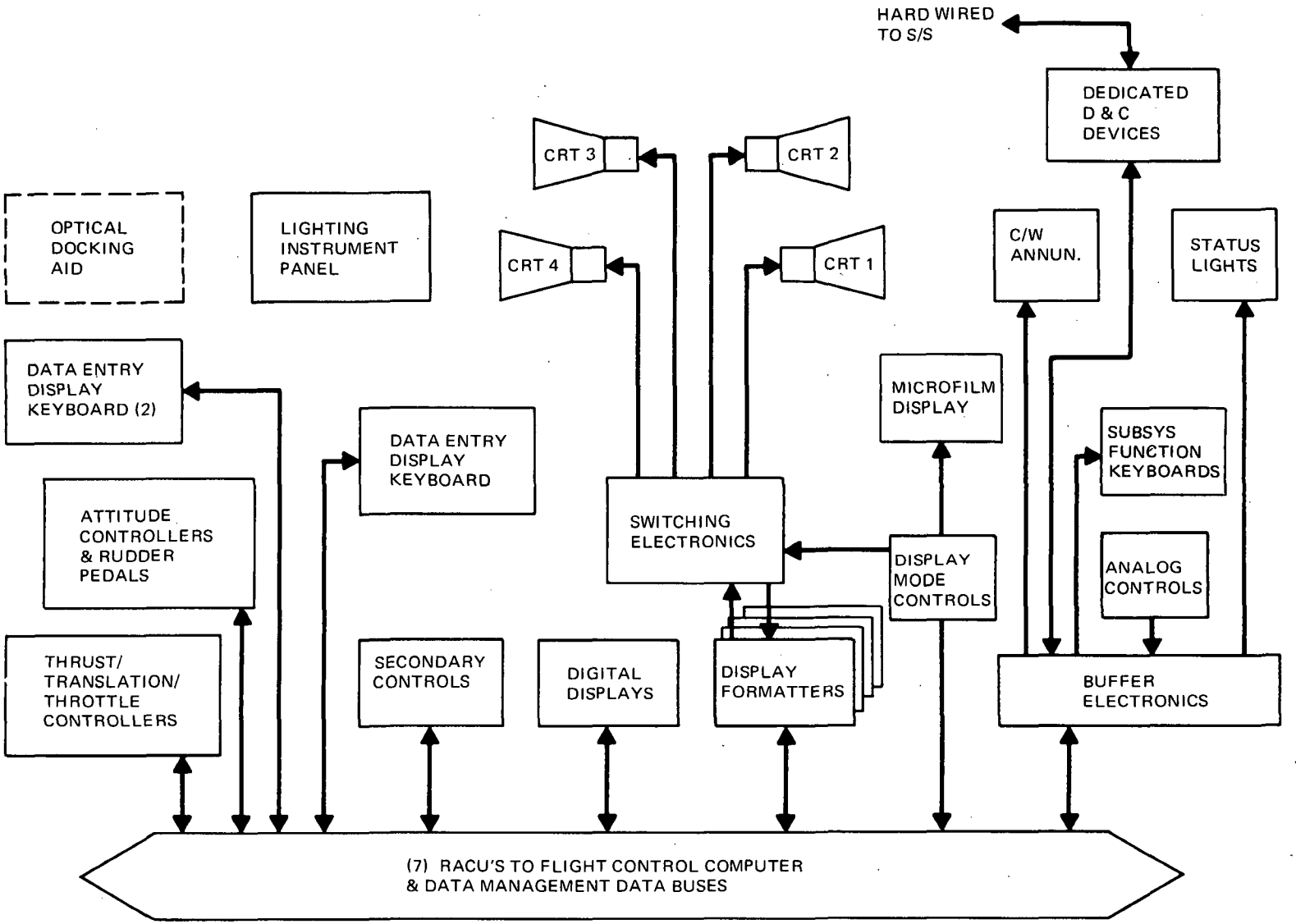


Fig. 5.5-1 Displays and Controls Block Diagram

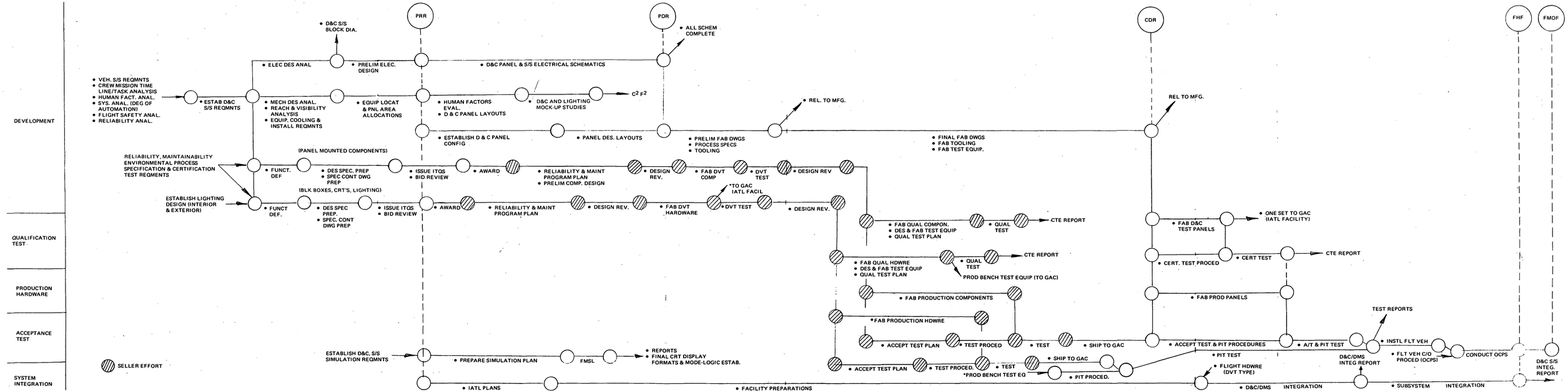


Fig. 5.5-2 Displays & Controls Logic Network



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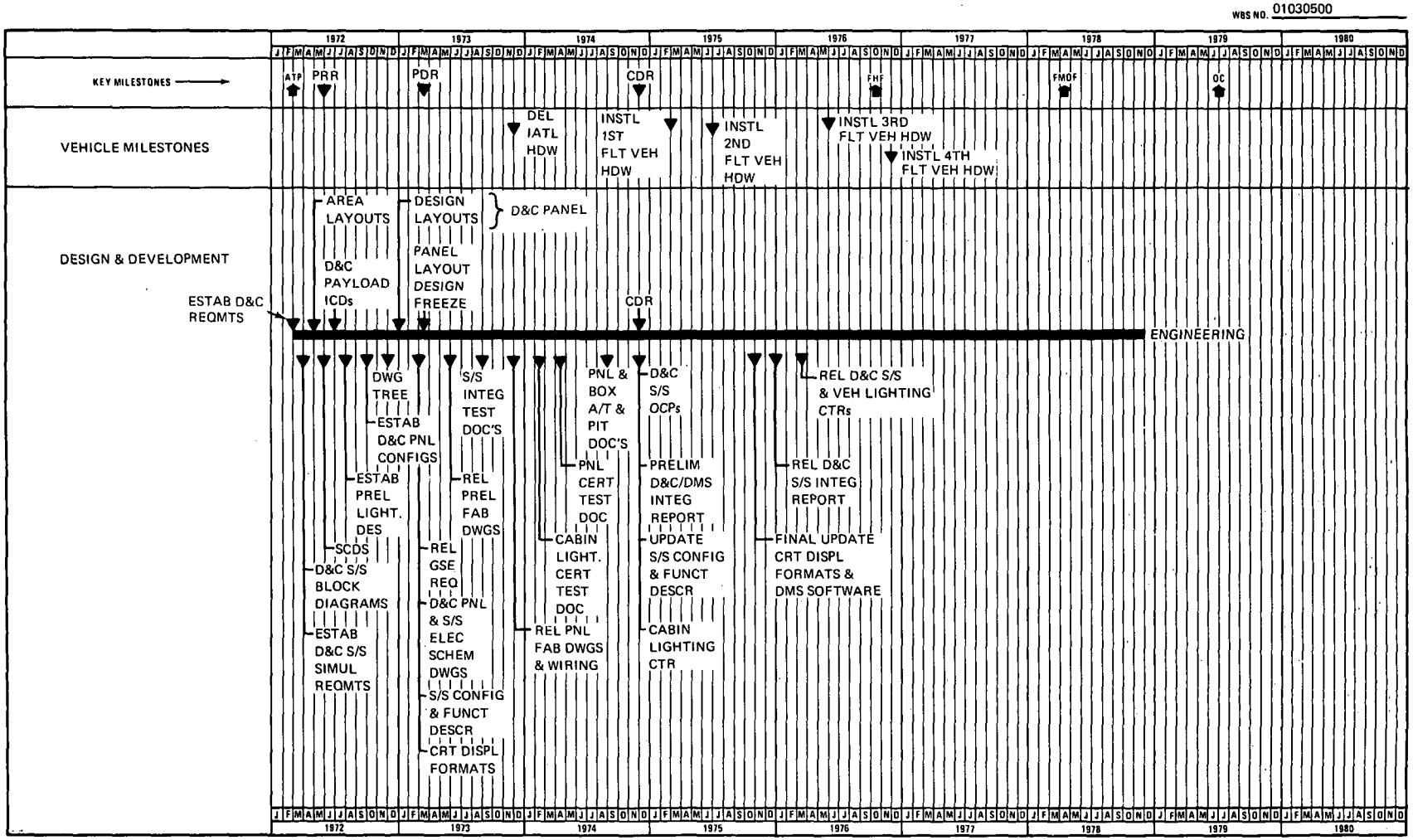








Fig. 5.5-3 Avionics Display & Controls Schedule (Sheet 1 of 3)

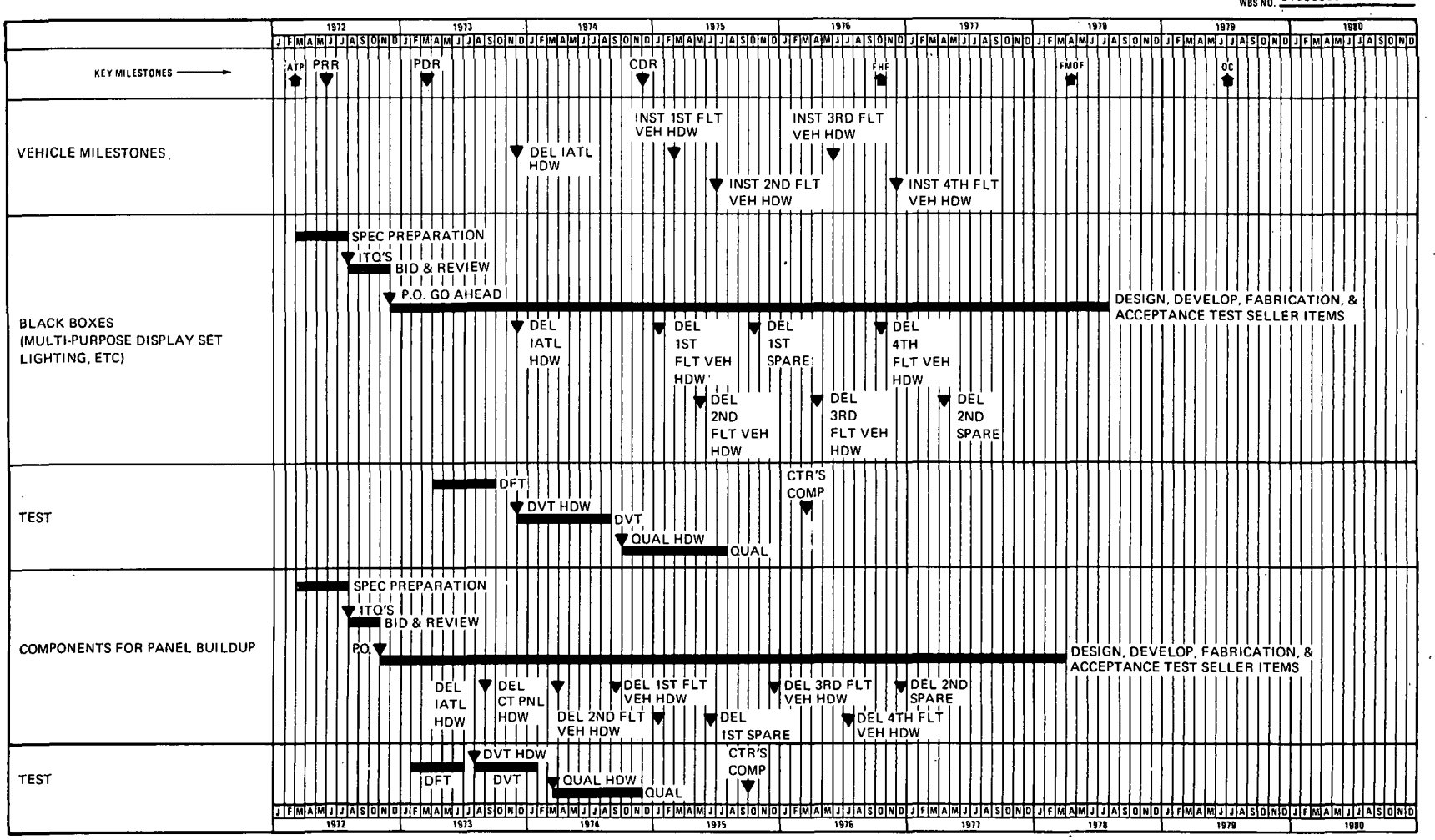


Fig. 5.5-3 Avionics Display & Controls Schedule (Sheet 2 of 3)

WBS NO. 01030500 AVIONICS

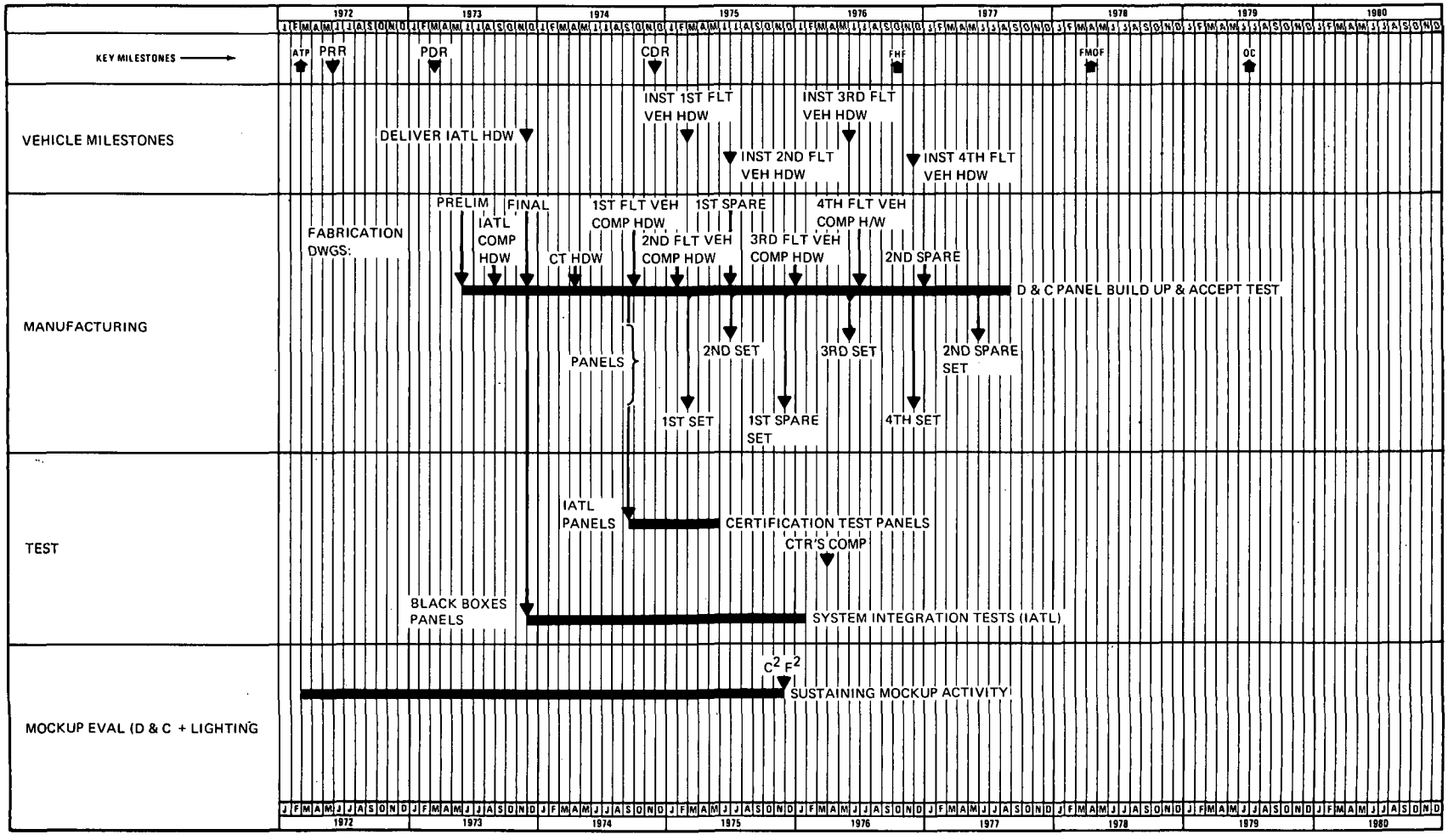


Fig. 5.5-3 Avionics Display & Controls Schedule (Sheet 3 of 3)

TABLE 5.5-1 D & C SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 5)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • D&C subsystem functional requirements | | | | | | | | | | | |
| - Ability to provide display and control* of all vehicle functions required for both horizontal and vertical flight | | X | | | | | | | | X | X |
| - Display and control functional compati-* bility with the simultaneous operation of all interfacing subsystems | | X | | | | | | | | X | X |
| - Ability of the C&W and OBC display* function of the D&C subsystem to alert the crew and provide display of data pertaining to system malfunctions | | X | | | | | | | | X | X |
| - Adequacy of interlocking and priority* logic to prevent inadvertent actuation of hazardous functions | | X | | | | | | | | X | |
| - Ability of D&C components, and black* box assemblies, to operate within desired performance tolerances under environmental and EMI specified test conditions | | | | | X | X | | | | | X |

*Constraint to first horizontal flight

TABLE 5.5-1 D & C SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 5)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Display test requirements | | | | | | | | | | | |
| - Ability of CRT displays and associated circuitry to provide adequate high-contrast, flicker-free displays | | X | | | | | | X | | X | |
| - Ability to display required information* formatted for efficient crew utilization (multipurpose display set and data entry/keyboard display CRT's) | | X | | | | | | | | X | X |
| - Ability of alpha-numeric displays and* associated electronics to provide satisfactory displays | | X | | | | | X | | | X | X |
| - Ability of instruments, C&W, annun-* ciators, and indicators to provide satisfactory displays. | | X | | | | | X | | | X | X |
| - Ability of the displays/data manage-* ment complex to provide adequate and timely responses to crew-initiated data display requests | | X | | | | | | | | X | X |
| - Ability of the combined displays to* provide priority information (C&W, OBC, etc.) with descending orders of attention-calling alerts and levels of system status | | X | | | | | | | | X | X |

TABLE 5.5-1 D & C SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 5)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| - Ability to provide a satisfactory auto-* built-in-test capability and status display for major D&C subsystem elements | X | | | | | | | X | | X | |
| - Ability to provide redundant display* operation and switching | X | | | | | | | X | X | X | |
| - Ability to provide automatic and man-* ual display of handbook type information from self-contained data file | | | | | | | X | | X | X | |
| - Adequacy of display data update rates* | | X | | | | | | | | X | |
| • Control test requirements | | | | | | | | | | | |
| - Verify that all crew station controls* respond properly and provide the desired command/control capability over other subsystems & DMS | | X | | | | | | | | X | |
| - Verify ability of controls to provide* the desired override of automated vehicle functions | | X | | | | | | | | X | |
| - Verify controls are situated for* efficient crew utilization and are compatible for both horizontal and vertical flight | X | X | | | | | | | | | X |

*Constraint to first horizontal flight

TABLE 5.5-1 D & C SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 4 of 5)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| - Verify adequate redundancy of controls* where necessary to assure mission objectives and safe return | | X | | | | | | | | X | |
| - Verify commonality, where possible, in control placement in dual cockpits to minimize crew training | | X | | X | | | | | | | |
| • Lighting requirements | | | | | | | | | | | |
| - All external lighting to be compatible* with safety of flight, FAA, and mission requirements | | X | | | | | | | | | X |
| - Cabin lighting to be self-adaptive to maintain a constant pre-set level of illumination and adequate crew visibility | | X | | | | | | | | | X |
| - Cabin and external lighting to be strategically located to prevent glare or reflections from cockpit windows | | X | | | | | | | | | X |
| - Instrument and panel lighting to be integrated into a uniform arrangement with maximum consideration for function and crew requirements | | X | | | | | | | | | X |

* Constraint to first horizontal flight

TABLE 5.5-1 D & C SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 5 of 5)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • In-process acceptance checkout requirements | | | | | | | | | | | |
| - Verify that all display and control hardware assemblies, PNL's, etc., are in accordance with design control specifications, process specifications, associated drawings, and are functionally compatible with next assembly requirements | | | | | | X | | X | X | | |
| - Verify cabin and external lighting to be in accordance with design standards | | X | | | | | | | | | X |

TABLE 5.5-2. MAJOR COMPONENT LIST

| Comp No. | Component Description | Qty/ Vehicle | Weight Each (lbs) | Size Each ($in^3$) | Power Each (Average Watts) |
|---|---|---|---|---|---|
| 1 | Multipurpose display units | 4 | 26.0 | 1128 | 130 |
| 2 | MDS switching electronics | 1 | 5.0 | 150 | |
| 3 | MDS formatting electronics | 4 | 46.0 | 1800 | 175 |
| 4 | Data entry/display keyboard | 2 | 30.0 | 2688 | 80 |
| 5 | Microfilm reader | 1 | 24.0 | 1120 | 100 |
| 6 | Solid state keyboards | 15 | 4.0 | * | 3 |
| 7 | C&W annunicators | 6 | 0.5 | * | 1 |
| 8 | Mission clock | 1 | 2.5 | * | 3 |
| 9 | Event timer | 2 | 2.0 | * | 3 |
| 10 | Digital displays | 5 | 2.0 | * | 3 |
| 11 | Interface electronics | 1 | 12.0 | 345 | 75 |
| 12 | Misc components | - | 52.3 | * | |
| 13 | Lighting Listed in Subsection 3.5.1.3 will be procured under this section | | | | |

*Panel-mounted



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TABLE 5.5-3 REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv Units |
|---|---|
| • Flight hardware per vehicle | 1 |
| • Component devel & qual test | 2 |
| • Integration Tests | |
| - Full mission simulation lab | |
| - Integrated avionics test lab | 1 |
| - Flight controls hydraulic test lab | |
| - Mechanical systems test rigs | |
| - Propulsion fluid breadboards | |
| - Escape system test rig | |
| • Test articles | |
| - Propulsion test article | |
| - Structural test article | |
| • Spares for flight test program | 2 |
| • Spares for 445 flights | |

TABLE 5.5-4 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Equipment | | | | |
| • Multipurpose display set (CRTs) | X | | | |
| • MDS switching electronics | X | | | |
| • MDS formatting electronics | X | | | |
| • Data entry/disp keyboards | X | | | |
| • Microfilm reader | X | | | |
| • C&W annunciators | X | | | |
| • Mission clock | X | | | |
| • Event timer | X | | | |
| • Digital displays (A/N) | | X | | |
| • Misc components | | X | | |
| • Interface electronics | | | X | |
| • Mode and function keyboards | | | X | |

TABLE 5.5-5 SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • D&C test bench with computer simulator<br>• Portable D&C test bench to be used in in-house test program |
| Software | • Programs to develop and modify CRT display formats (refer to Section 12)<br>• Programs to simulate DMS interface (refer to Section 12) |
| | |

TABLE 5.5-6 FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Gov |
|---|---|---|---|---|
| • Interactive graphics disp terminal required to develop display formats and prove out DMS/D&C interface software | X | | | |
| • D&C panel final assembly and test (Apollo LM) | | X | | |
| • FMSL simulator facility* | X | | | |
| • IATL facility* | X | | | |
| • Lighting lab | | X | | |
| *Facility description and software requirements are covered in subsection 10.6 | | | | |

## 5.6 AVIONICS SUBSYSTEM DESIGN

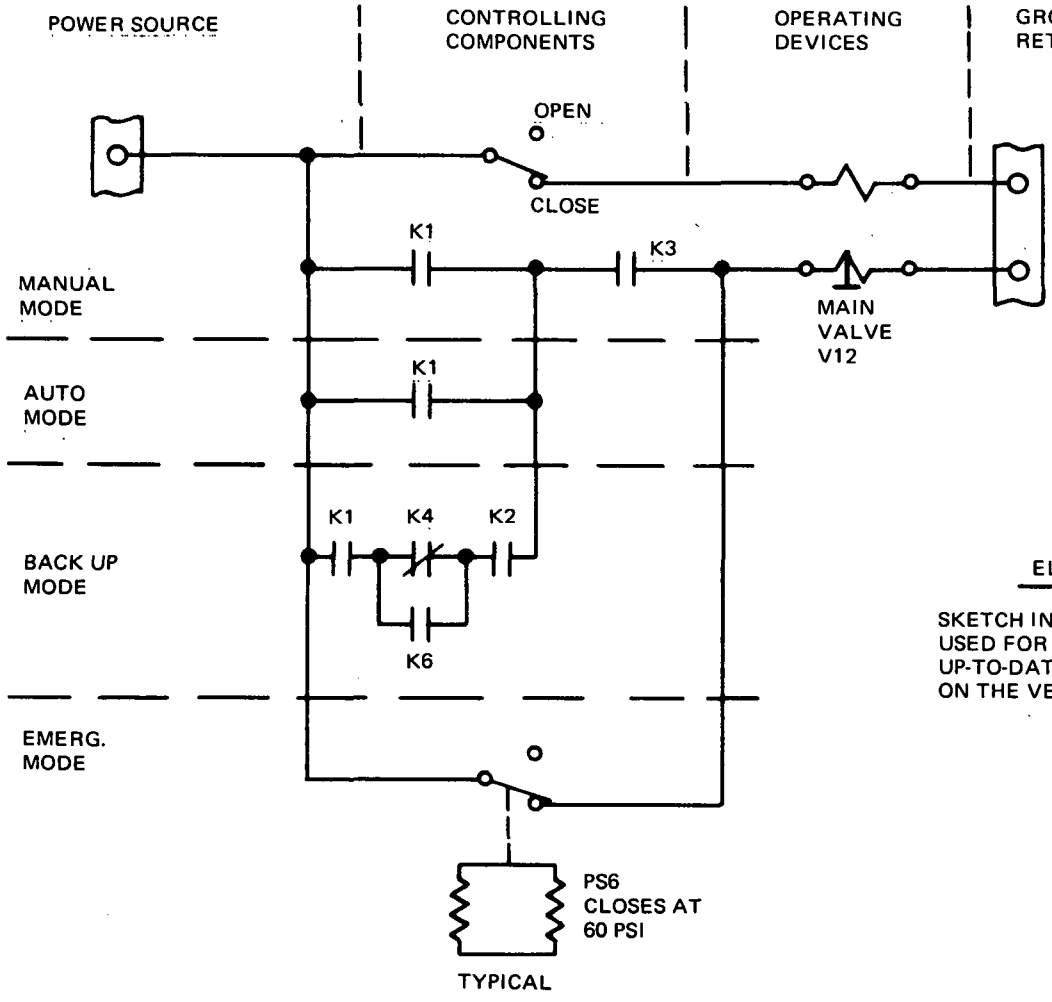
The avionics subsystem design function consists of:

- Definition of inter/intra subsystem interfaces and configuration control documentation (functional and wiring schematics)
- Design of the vehicle cable system
- Provisions of hardware not contained within subsystem equipment
- Determination of equipment packaging, location, and installation requirements throughout the vehicle
- Design and specification of distribution centers, control panels, and miscellaneous Grumman-fabricated electrical assemblies
- Provision of data and design support mock-up, test, and development aids

The design approach includes:

- Generation of configuration schematics and data for hardware development operation and fabrication using:
  - Elementary functional diagrams (EFD) - subsystem oriented defining interfaces, circuitry, and operation in booklet format
  - Wiring schematics - subsystem oriented for circuitry and hardware development
  - Interconnection schematics - vehicle area oriented interfacing equipment, wiring, and vehicle requirements.
  - Electronic data automation (EDA) - computer-controlled wiring configuration and fabrication data
- Cable system for interconnecting equipment features wire crimp/weld terminations of prefabricated circular polyimide-insulated harness containing spare conductors using junction boxes or mated connectors for system distribution

- Cable system design integrated on a equipment lines mock-up (ELM) for routing and interface definition
- Majority of avionics equipment located in pressurized cabin area
- Integration and modularization of power and data management requirements for subsystem interfaces at distribution centers located for regional control of all subsystem equipments
- Standardization and control of equipment/component form factors, including thermal control, as line-replaceable units
- Certification testing of Grumman electromechanical fabrications




## ELEMENTARY FUNCTIONAL DIAGRAMS (EFD)

SKETCH INDICATES THE METHOD OF DEVELOPMENT CONTROL USED FOR ALL CIRCUITRY REQUIREMENTS. IT REPRESENTS UP-TO-DATE CIRCUITRY OF AN INDIVIDUAL SYSTEM FUNCTION ON THE VEHICLE. FEATURES ARE:

- DEVELOPING ENGINEERING CONCEPTS
- EXPLANATION OF SYSTEM FUNCTIONS
- AID TO SHOOTING TROUBLE
- AID TO MONITORING OF REVISIONS
- CONTROL MEDIA IN OPERATION ON LM & F-14

EFD LAYOUTS TRACE THE SIGNAL/POWER FLOW OF THE SYSTEM IN A SINGLE LINE FORMAT (DRAWN LEFT TO RIGHT, SEEKING GROUND) INDICATING CONTROLLING COMPONENTS AND OPERATING DEVICES IN VARIOUS MODES. PUBLISHED IN BOOKLET FORMAT.

Fig. 5.6-1 EFD Schematics

LM VEHICLES CONNECTOR LIST — LM-10 CONNECTOR LIST ASSY NO. LDWLED390-112 — DATE 11/03/70

| FROM | SHLD/ TWIST CODE | TO | SHLD/ TWIST CODE | WIRE TYPE CODE | WIRE(G1Q & Q-T*Q JYQQE N | | | EMI, SIGNAL L' G2Q J*QQJYK5 Q-Q & QCT G1QEFB CODE | COLOR | ASSEMBLY NUMBER | REV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| E2528 | | P1419-K | | H | P 116C | 18 | 78 | A | NAT | 390-58110-5 | C7 |
| E2528 | | P257A-G | | F | P 229D | 14 | 60 | A | NAT | 390-58110-5 | C7 |
| E2529 | | E2528 | | F | P 229N | 14 | 20 | A | NAT | 390-58110-5 | C7 |
| E2529 | | P1419-M | | H | P 163B | 18 | 81 | A | NAT | 390-58110-5 | C7 |
| E2529 | | 4K3-4 | | F | P 229L | 14 | 22 | A | NAT | 390-58110-5 | C7 |
| E2529 | | 4K4-4 | | F | P 229M | 14 | 24 | A | NAT | 390-58110-5 | C7 |
| E253 | T2CB | J260-3 | T2CB | X | D 4701B | 26 | 18 | E | BLK | 390-59416-3 | |
| E253 | T2CA | J288-H | T2CA | X | D 4701A | 26 | 132 | E | BLK | 390-59416-3 | |
| E2530 | B-AM | P189-43 | E-AM | P | A 124F | 22 | 46 | H | NAT | 390-58101-11 | D |
| E2530 | T2CG | 9M1-AIA31NAT | T2CG | | | | | NOTE12+57 | NAT | 390-58101-11 | C |
| E2530 | B-AX | 9S29-8 | E-AX | P | A 124G | 22 | 24 | H | NAT | 390-58101-11 | C |
| E2530/SHLD | B-AM | E2534/SHLD | | B | A 8000AS | 22 | 8 | H SHLD RET JUMPER | NAT | 390-58101-11 | D |
| E2530/SHLD | B-AM | E2612/SHLD | B-AX | B | A 8000AU | 22 | 8 | H SHLD RET JUMPER | NAT | 390-58101-11 | C |
| E2531 | B-AL | P189-24 | E-AL | P | A 125F | 22 | 46 | H | NAT | 390-58101-11 | D |
| E2531 | T2CF | 9M1-AIA29NAT | T2CF | | | | | NOTE12+57 | NAT | 390-58101-11 | D |
| E2531 | B-AW | 9S29-5 | E-AW | P | A 125G | 22 | 24 | H | NAT | 390-58101-11 | D |
| E2531/SHLD | B-AL | E2533/SHLD | | B | A 8000AY | 22 | 8 | H SHLD RET JUMPER | NAT | 390-58101-11 | C |
| E2531/SHLD | B-AL | E2611/SHLD | B-AW | B | A 8000BB | 22 | 8 | H SHLD RET JUMPER | NAT | 390-58101-11 | D |
| E2532 | B-AK | P189-45 | E-AK | - | A 126X | 22 | | H | BLK | 390-58101-11 | D |
| E2532 | B-AS | TB1-14 | E-AS | - | A 126Y | 22 | | H | BLK | 390-58101-11 | C |
| E2532 | T2DS | 9M1-AIA28BLK | T2DS | | | | | NOTE12+57 | BLK | 390-58101-11 | C |
| E2532/SHLD | | E2536/SHLD | B-AK | B | A 8000AW | 22 | 8 | H SHLD RET JUMPER | NAT | 390-58101-11 | C |
| E2532/SHLD | | E2610/SHLD | B-AS | B | A 8000AX | 22 | 8 | H SHLD RET JUMPER | NAT | 390-58101-11 | C |

THE ABOVE IS AN EXAMPLE OF COMPUTER CONTROLLED WIRING CONFIGURATION AND FABRICATION DATA FOR DESIGN CONTROL FOR HARDWARE DEVELOPMENT





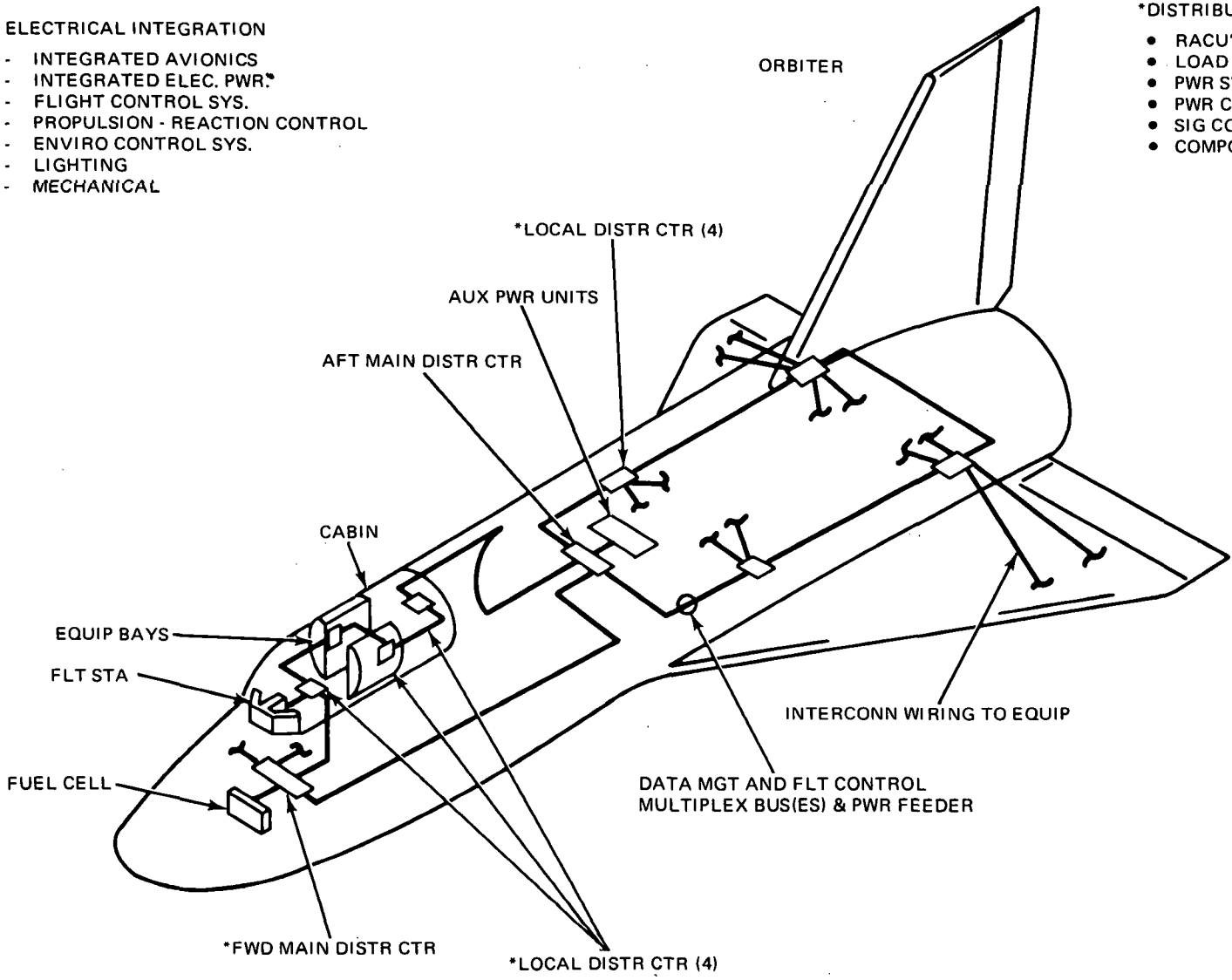
Fig. 5.6-2 Typical Electronic Data Automation

ELECTRICAL INTEGRATION

- INTEGRATED AVIONICS
- INTEGRATED ELEC. PWR.
- FLIGHT CONTROL SYS.
- PROPULSION - REACTION CONTROL
- ENVIRO CONTROL SYS.
- LIGHTING
- MECHANICAL

*DISTRIBUTION CTRS CONTAIN

- RACU'S
- LOAD CONTROLLERS
- PWR SWITCHING
- PWR CONDITIONING
- SIG CONDITIONING
- COMPONENT THERMAL CONTROL




SKETCH INDICATES THE METHODOGY OF EQUIPMENT PACKAGING & INSTALLATION

- AVIONICS IN PRESSURIZED & MAINTAINABLE CABIN
- MULTIPLEX & PWR FEED TERMINALS AT DISTR CENTERS
- DISTR CTR STRATEGICALLY LOCATED FOR REGIONAL CONTROL
- MODULAR PACKAGING

Fig. 5.6-3 Signal Multiplexing

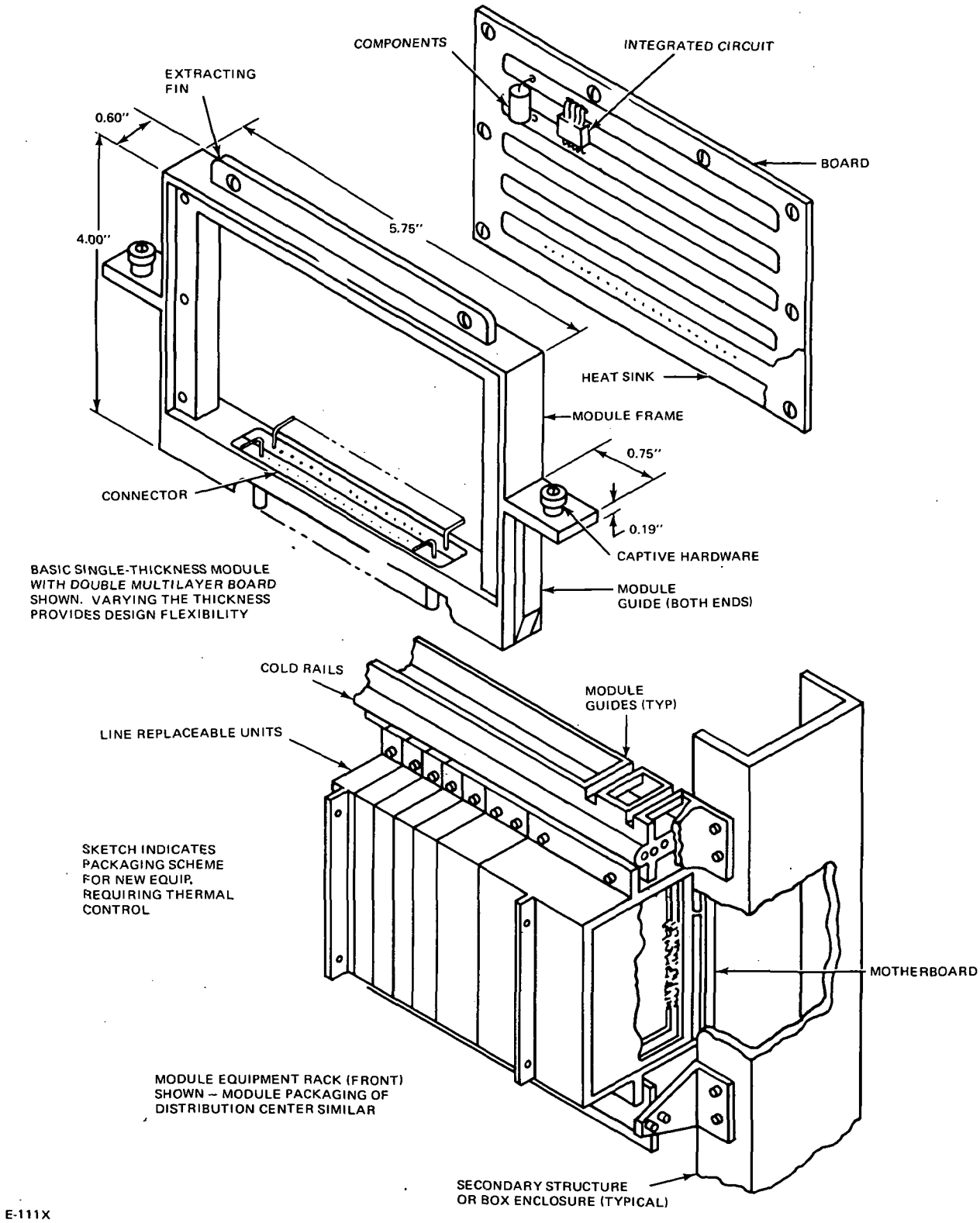
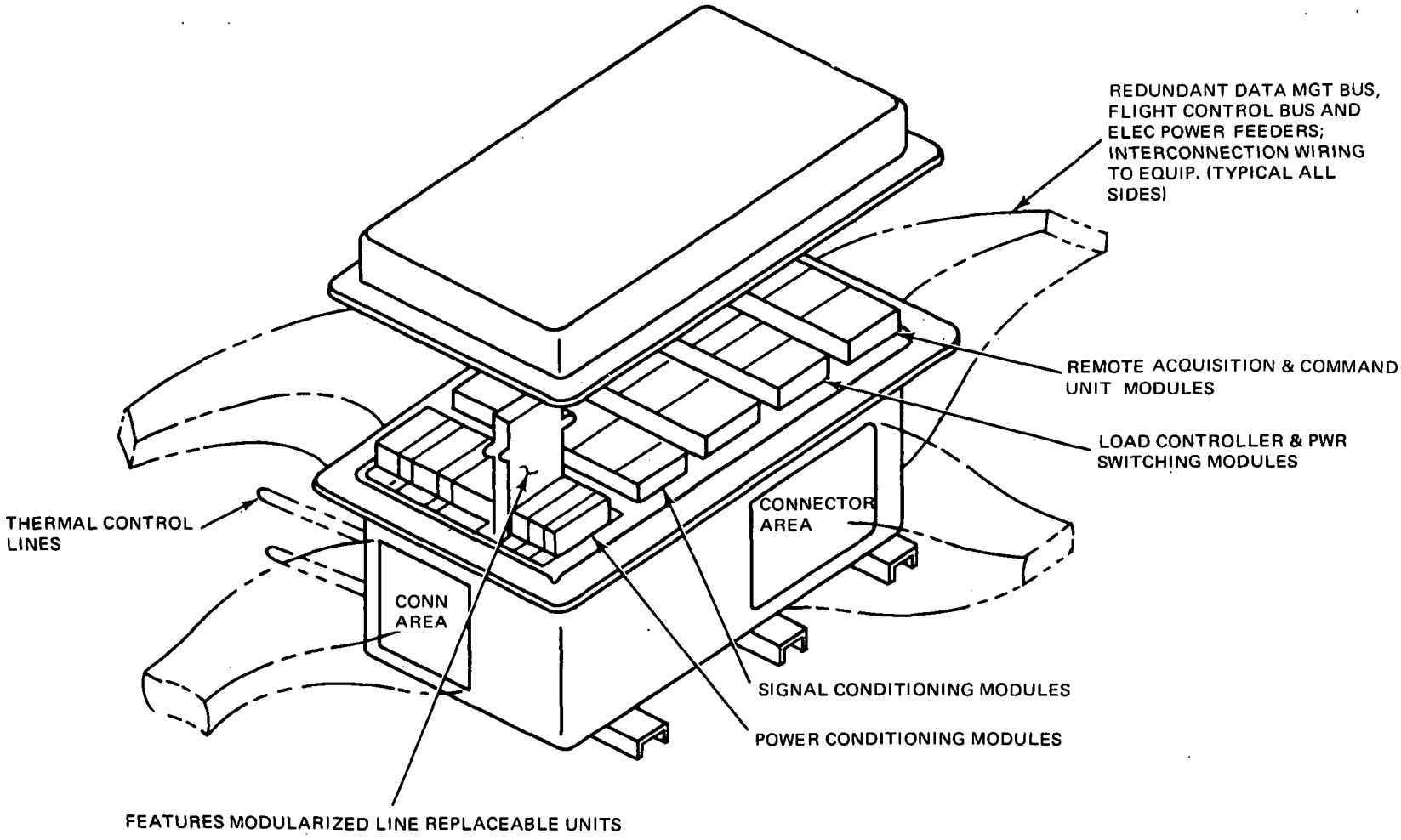



Fig. 5.6-4 Module and Rack




TYPICAL LOCAL DISTRIBUTION CENTER
FOR REGIONAL SUBSYSTEM CONTROL PROVIDES
COMPONENT THERMAL CONTROL FOR OPERATION
IN NON-PRESSURIZED AREAS OF AIRFRAME

Fig. 5.6-5 Distribution Center

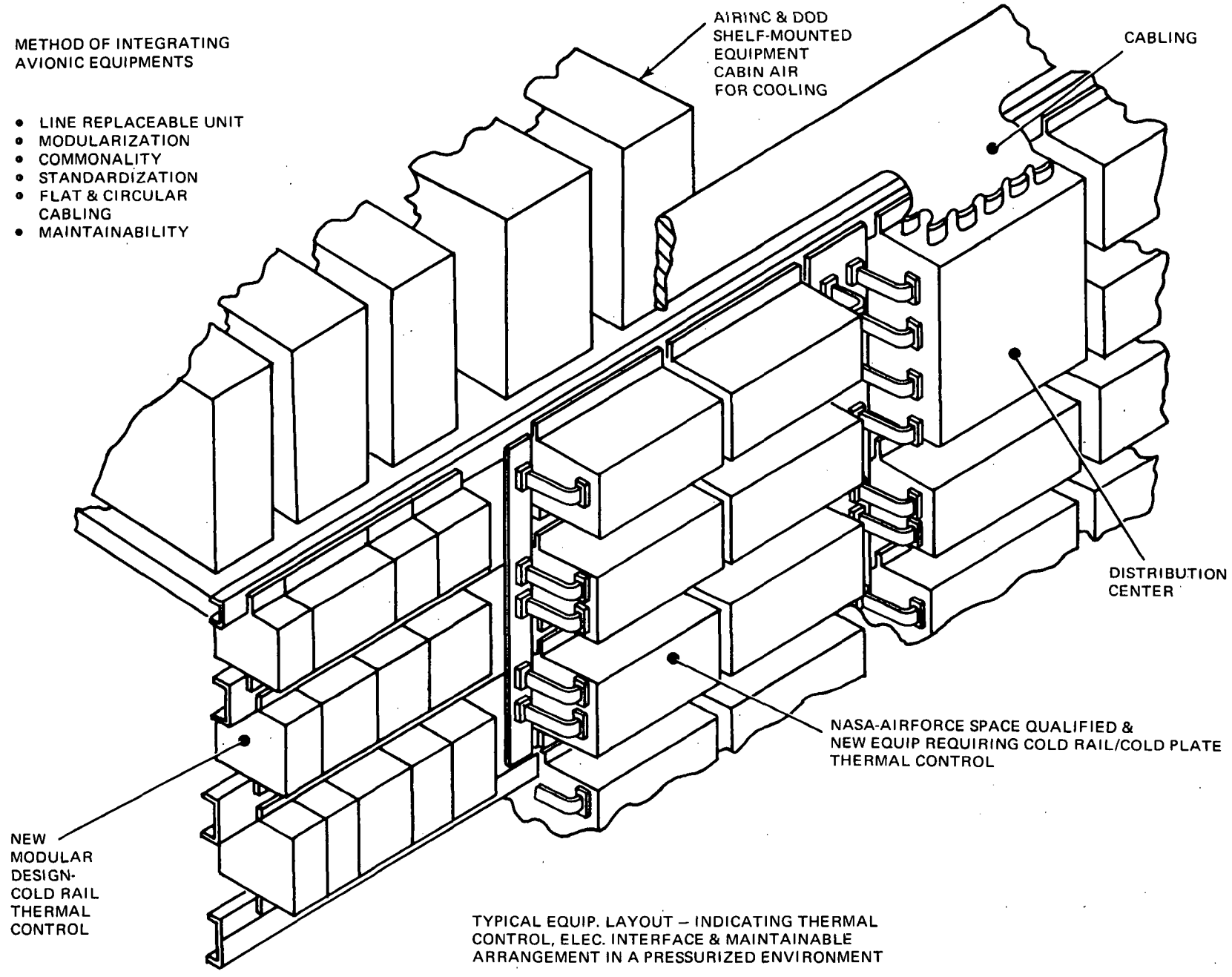
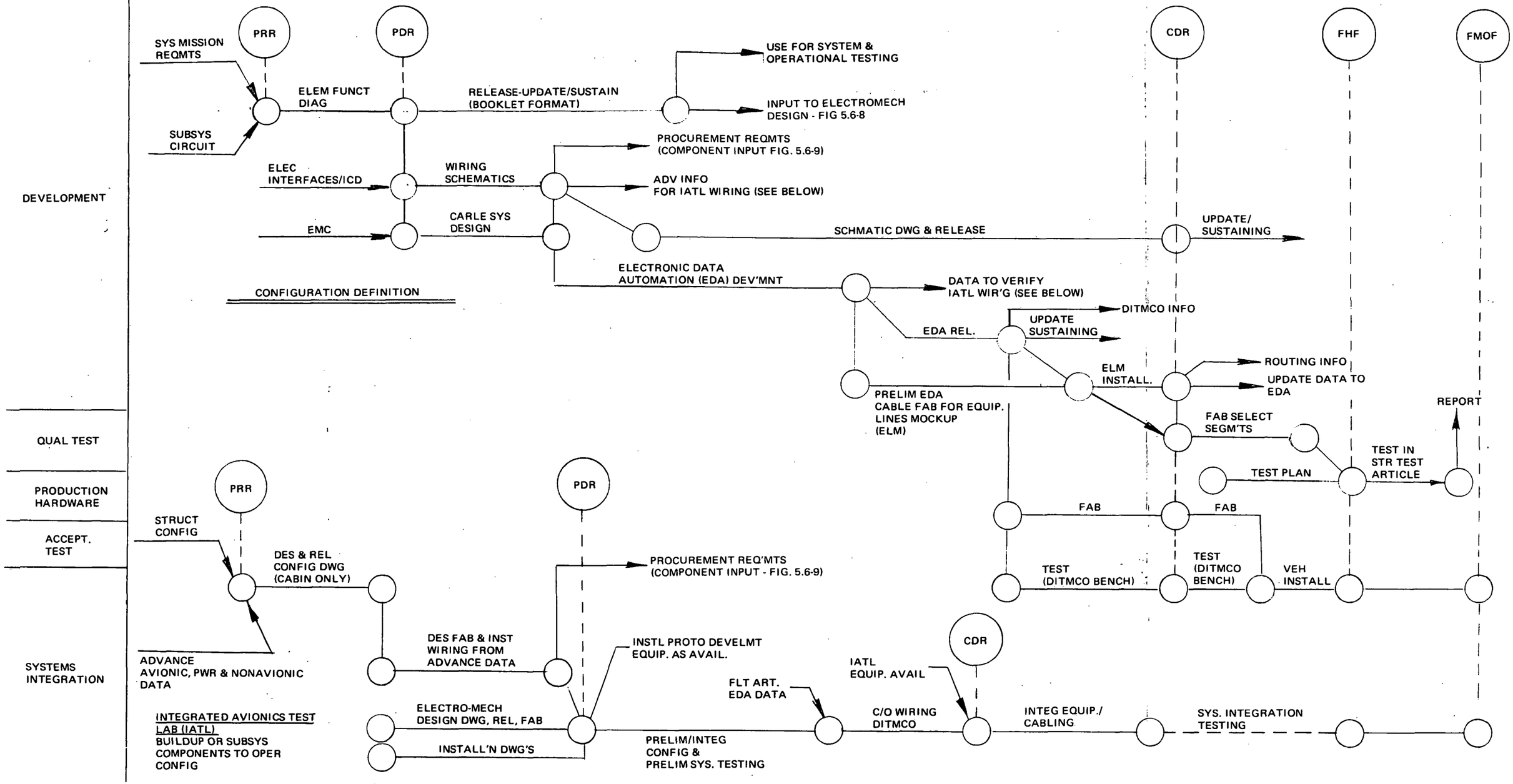



Fig. 5.6-6 Typical Equipment Layout




E=182

Fig. 5.6-7 Avionics Subsystem Design Logic (Configuration Definition and Integrated Test)

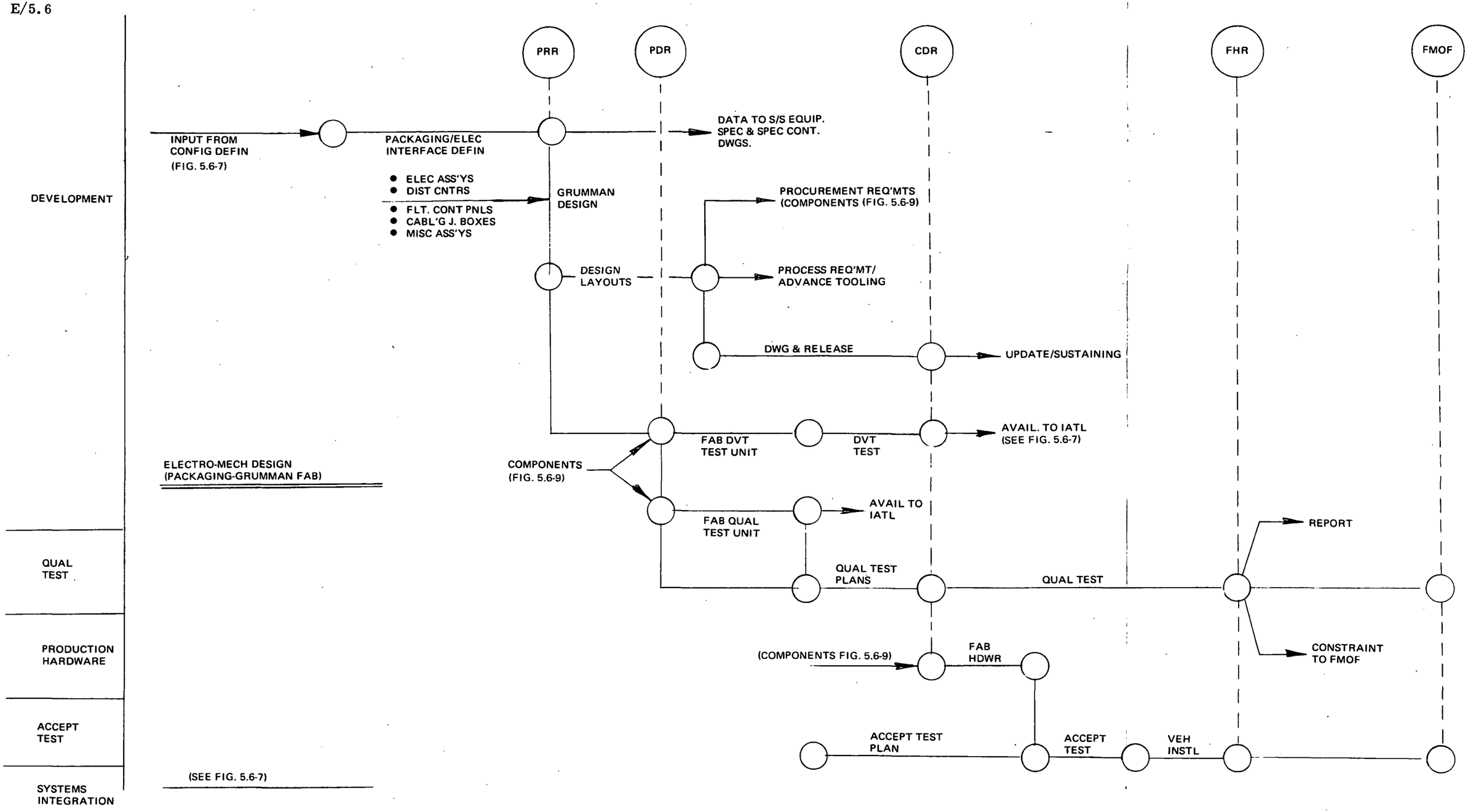



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Fig. 5.6-8 Avionics Subsystem Design Logic (Electro-mechanical Design)



GRUMMAN BOEING

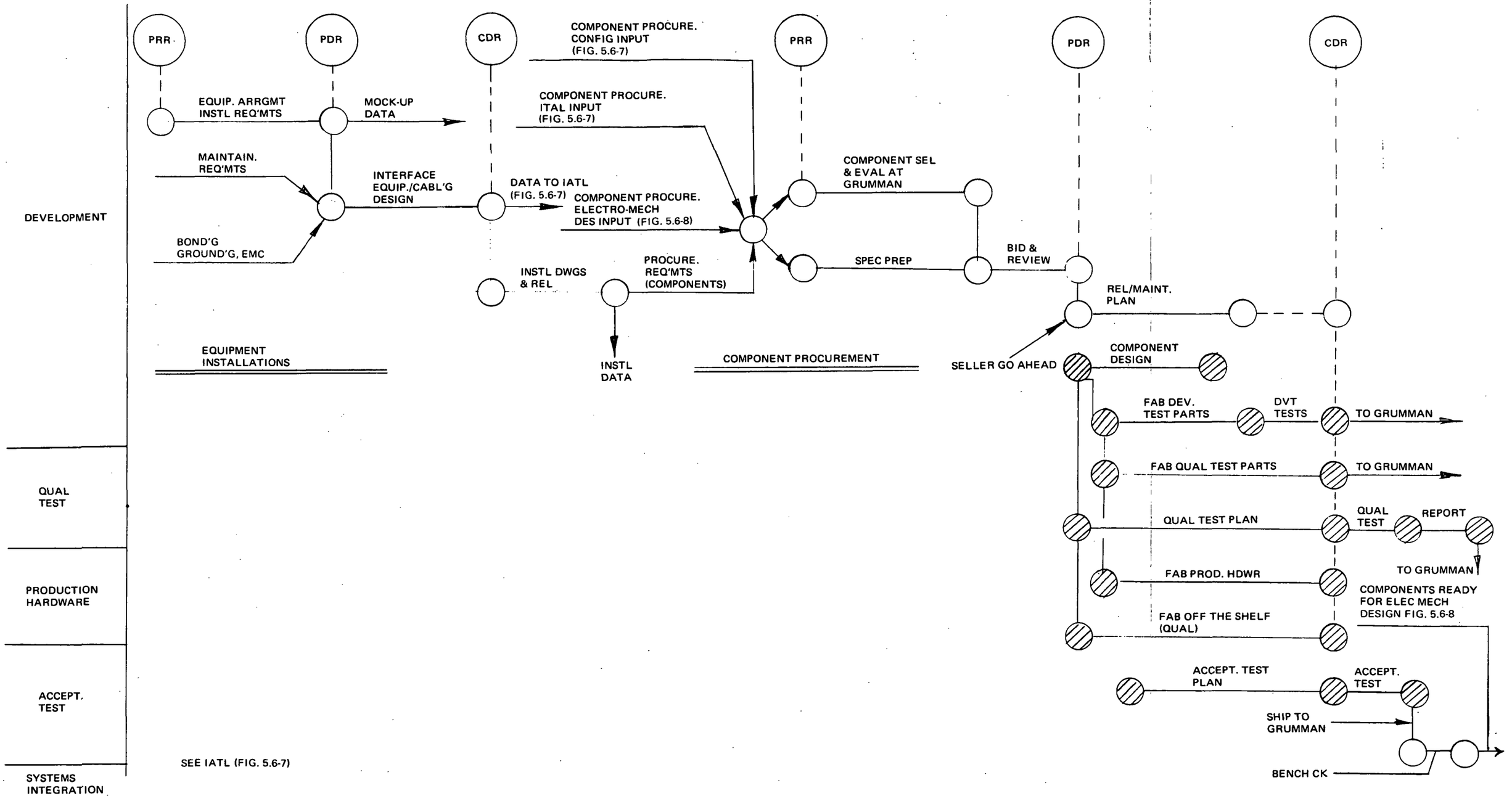


Fig. 5.6-9 Avionics Subsystem Design Logic (Equipment Installation and Component Procurement)

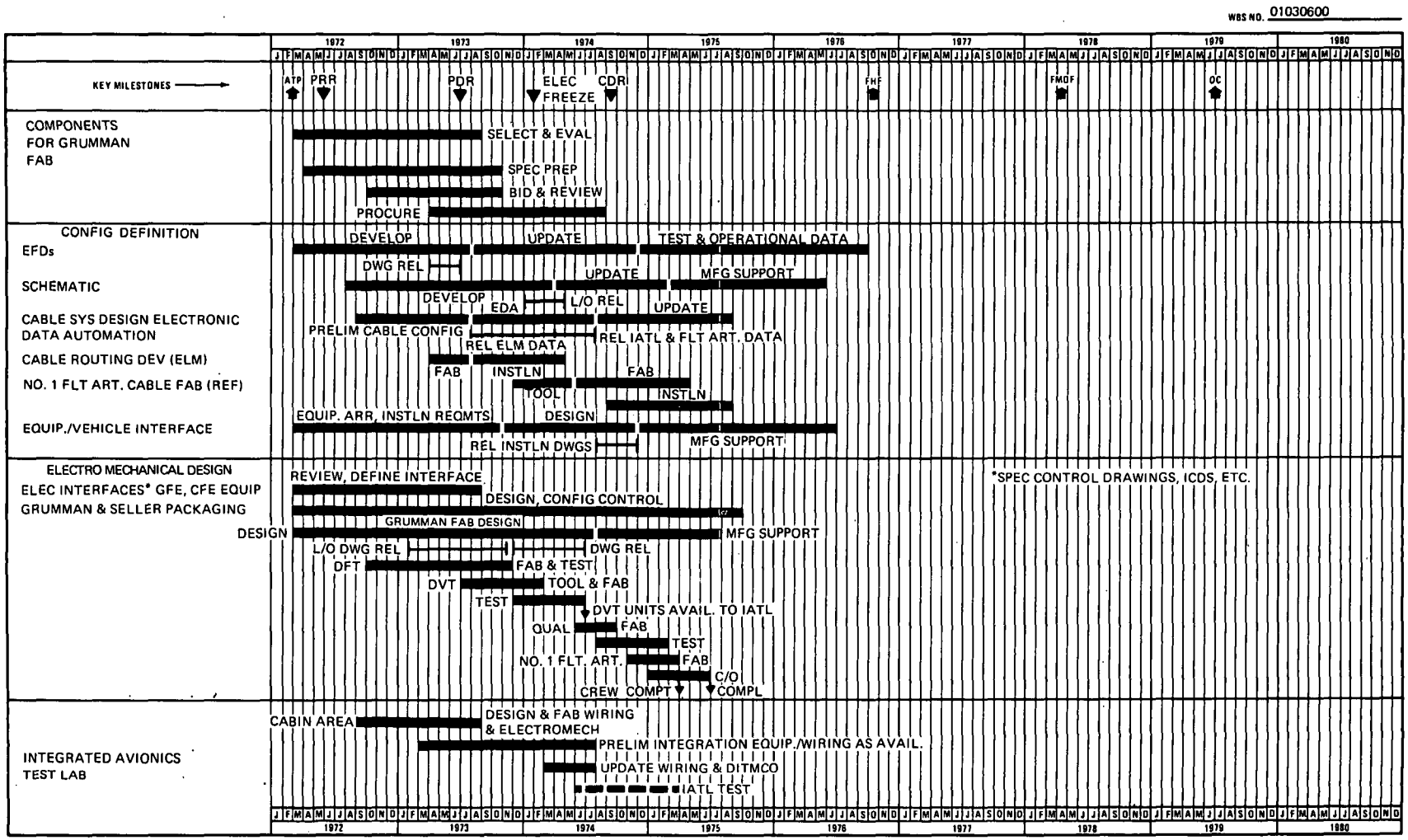


Fig. 5.6-10 Avionics Subsystem Design Schedule

TABLE 5.6-1 CERTIFICATION REQUIREMENTS (Sheet 1 of 6)

| Certification Requirement Performance (Note 1) | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | Devel | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Avionic, Power supply, and distribution installations | | | | | | | | | | | |
| - Verify that provisions are adequate for the mechanical support, EMC restrictions, bonding, shielding requirements, connect/disconnect devices, and to protect the LRU's from all operational environments, i.e., shock, vibration, contamination, vacuum, etc. | X | X | | | | | | | | X | X |
| - Verify that provisions are adequate for thermal control of the components of the LRU's that require close regulation | X | | | | | | | | | X | X |
| • Intravehicle flight wiring interfaces | | | | | | | | | | | |
| - Verify the adequacy of the intravehicle flight wiring and associated electrical hardware for interconnection of orbiter subsystem equipments, both GFE and CFE | X | X | | | | | | | | | X |
| - Verify the adequacy of the intravehicle flight wiring and associated electrical hardware for interconnection of GSE terminals, i.e., external power, racu, off vehicle equipment electrical interfaces, etc. | X | X | | | | | | | | | X |

TABLE 5.6-1 CERTIFICATION REQUIREMENTS (Sheet 2 of 6)

| Certification Requirement Performance (Note 1) | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | Devel | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| - Verify the adequacy of the intravehicle flight wiring and associated electrical hardware for the assigned mission payload configuration per ICD (TBD) | X | X | | | | | | | | | X |
| - Verify the adequacy of the intravehicle flight wiring and associated electrical hardware to accept the launch tower transferring umbilical requirements of electrical control monitoring, and power per ICD (TBD) | X | X | | | | | | | | | X |
| - Verify the adequacy of the intravehicle flight wiring and development flight instrumentation (DFI) interface | X | X | | | | | | | | | X |
| • Intervehicle flight wiring interfaces | | | | | | | | | | | |
| - Verify the adequacy of the intervehicle flight wiring and associated electrical hardware for hardwire interconnection to provide transfer of electrical control, monitoring, separation activation, and power as required for the $H_2$ external tanks interface | X | X | | | | | | | | | X |

TABLE 5.6-1 CERTIFICATION REQUIREMENTS (Sheet 3 of 6)

| Certification Requirement Design (Note 1) | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | Devel | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Avionics and power distribution packaging line replaceable unit (LRU) | | | | | | | | | | | |
| - Verify that the avionics and power distribution sybsystem elements are designed to include the capability to fault-isolate to the LRU level (including standby units) with replacement capability any time prior to launch | X | | | | | | | | | | X |
| - Verify that removal or replacement of a faulty LRU shall not require the removal of other LRU's, nor the breaking of any functional flight connections other than those required for the removal of the faulty unit, and without adversly effecting the associated connectors, devices, or wiring | X | | | | | | | | | | X |
| - Verify that the LRU's and associated connectors/devices and support chassis preclude mismating or misapplication within the vehicle or electrical assemblies (for modularized plug-in LRU's) | X | | | | | | | | | | X |
| • Inter-intra flight wiring (Grumman fabrications) | | | | | | | | | | | |
| - Verify that cabling configuration provides accessibility for inspection, maintenance, and protection from mechanical damage and contamination | X | | | | | | | | | | X |

TABLE 5.6-1 CERTIFICATION REQUIREMENTS (Sheet 4 of 6)

| Certification Requirement Design (Note 1) | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | Devel | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| - Verify that electrical connectors/ devices capable of being readily mated and demated shall be provided for wiring/cabling terminations at all subsystems electrical/electronic equipments or LRU's | X | | | | | | | | | | X |
| - Verify that redundant wiring/cabling is separated to minimize the probability of sustaining damage to the redundant paths simultaneously | X | | | | | | | | | | X |
| - Verify that umbilicals and associated connectors that require manual mating/demating while on mission are designed for stowage, handling, and connecting in zero "g" environment | X | | | | | | | | | | X |
| - Verify that non-destructive deadfacing is provided for power and other susceptible control cables requiring connection during the mission, or during ground service prior to mating/ demating of quick release or zero "g" connector/devices | X | | | | | | | | | | X |
| - Verify that cabling is separated and routed in accordance with EMI requirements | X | | | | | | | | | | X |

TABLE 5.6-1 CERTIFICATION REQUIREMENTS (Sheet 5 of 6)

| Certification Requirement Design (Note 1) | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | Devel | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| - Verify that cable system junction boxes provide the integrity of electrical and mechanical components, EMC restrictions, bonding, shielding requirements, connect/disconnect devices, and performance in all operational environments, i.e., shock, vibration, contamination, vacuum, etc. | | | | | X Note (1) | X Note (2) | | X | | | |
| • Electrical integration enclosures and control panels (Grumman fabrications) | | | | | | | | | | | |
| - Verify that the distribution centers provide the following functions and interface in accordance with the applicable subsystem: | | | | | X Note (1) | X Note (2) | | X | | | |
| o Remote acquisition command (RACU) units | | | | | | | | | | | |
| o Power control, conditioning, and distribution | | | | | | | | | | | |
| o Signal conditioning | | | | | | | | | | | |
| o Component thermal control | | | | | | | | | | | |
| o Data management and flight control multiplex bus(s) and power feeder interface | | | | | | | | | | | |

TABLE 5.6-1 CERTIFICATION REQUIREMENTS (Sheet 6 of 6)

| Certification Requirement Design (Note 1) | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | Devel | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| In addition, verify that the distribution centers provide integrity of the electrical and mechanical components, EMC restrictions, bonding, shielding requirements, connect/disconnect devices, and performance in all operational environments, i.e., shock, vibration, contamination, vacuum, etc. | | | | | | | | | | | |
| - Verify that the flight control panels, electrical assemblies, junction and relay boxes, etc., provide the functional control and interface in accordance with the subsystem requirements and that the integrity of the electrical and mechanical components, EMC restrictions, bonding, shielding requirements, and connect/disconnect devices, and perform in all operational environments, i.e., shock, vibration, contamination, vacuum, etc. | | | | | X Note (1) | X Note (2) | | X | | | |

Notes (1) All performance and design certification requirements noted are constraints to first horizontal flight (FHF) and shall be verified adequate prior to FHF.

(2) The electrical integration enclosures and control panels (Grumman fabrications) shall be fully qualified to perform in all operational environments prior to first manned orbital operation.

TABLE 5.6-2 MAJOR COMPONENT LIST

| Comp No. | Component Description | Qty/ Vehicle | Weight Each (lbs) | Size Each | Power Each | Remarks |
|---|---|---|---|---|---|---|
| 1 | Cabling system (includes wire, connectors, and sundries) | Harness set | 1100 | NA | NA | Grumman fabricated |
| 2 | Cable junction box | 24 | 4 | 320 $in.^3$ | None | Grumman fabricated |
| 3 | Fwd main distr assy (See Note) | 1 | 36 | 3.7 $ft^3$ | None | Grumman fabricated |
| 4 | Aft main distr assy (See Note) | 1 | 32 | 3.5 $ft^3$ | None | Grumman fabricated |
| 5 | Local distr assy-A (See Note) | 4 | 37 | 3.2 $ft^3$ | None | Grumman fabricated |
| 6 | Local distr assy-B (See Note) | 4 | 10 | 1.0 $ft^3$ | None | Grumman fabricated |
| 7 | Control panels and misc electrical assemblies | 25 | 4 | 72 $in.^3$ Typical | TBD | Grumman fabricated |

Note: These assemblies package the power distribution and conditioning and data management (remote acquisition command unit-RACU) requirements and provide electrical, mechanical, and thermal interfaces. The weights indicate only the mounting, structure, electrical, mechanical, and thermal provisions for the components.

TABLE 5.6-3 REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv Units |
|---|---|
| • Flight Hardware per vehicle | 1 |
| • Component devel and qual test | 1 |
| • integration tests | |
| - Full mission simulation lab | |
| - Integrated avionics test lab | 1 |
| - Flight controls hydraulic test lab | |
| - Mechanical systems test rigs | |
| - Propulsion fluid breadboards | |
| - Escape system test rig | |
| • Test articles | |
| - Propulsion test article | |
| - Structural test article | |
| • Spares for flight test program* | 1 |
| • Spares for 445 flights* | 5 |

*Spare at component or modularized LRU level.

TABLE 5.6-4 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| • Cable system components<br>- Elec connectors, termination devices, & sundries<br>- Wire<br>- Encapsulants & processes | | X | | Common design problems exist between airframe fabricators for integration of equipment in the operational environment |
| • Components<br>- Load controllers<br>- Resistors, capacitors, transistors, etc.<br>- Switches, Relays, etc. | | X | | Program benefit from common source and alternate suppliers of components |
| • Packaging Schemes<br>- Modularization<br>- Standardization | | X | | Control of seller & in-house fabrications through specification control of form factor, mounting provisions, thermal and electrical interfaces (type, size, source) |
| • Electrical interfaces | | X | | |

TABLE 5.6-5 SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Grumman manufactured electromechanical assemblies (distribution centers (10), cable junction boxes (24), and control panel and misc elect. assemblies) require the following:<br>- Handling and checkout fixtures for sub and final assemblies during factory flow<br>- Shipping and handling fixtures at the line replaceable unit (LRU) level for installation/maintenance operations<br>- Equipment for development and acceptance testing; thermal vacuum equipment, shock and vibration, thermal control rig, adapter harnesses and sundries, and checkout consoles<br>• Grumman manufactured cable assemblies require the following:<br>- Handling and checkout fixtures during factory flow<br>- Interface cable harness to mate with vehicle cable system and equipment for checkout during routine maintenance and pre-flight activities including launch tower interfaces<br>- DITMCO equipment |
| Software | Program for DITMCO for checkout of cable harness at bench and after installation levels |

TABLE 5.6-6 FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Govt |
|---|---|---|---|---|
| • Development Testing | | | | |
| - Avionic & environmental test area (DFT, DVT & Qual Test req'mt) to be utilized for Grumman-fabricated electro-mechanical designs, i.e., distr. centers, cable J box, flight control panels, misc elec assy, etc. | | X | X | |
| - Component lab (plant 14) for component evaluation and test | | X | X | |
| • Manufacturing | | | | |
| - Cable fabrication and electromechanical assemblies facilities and checkout equipment to support proto, development testing, flt articles, and mockup activities | | X | X | |

# Section 6

# POWER

The power system is designed to supply the total electrical and hydraulic power requirements of the space shuttle orbiter in a seven day independent earth-orbital mission, and to provide fail operational/fail safe (FO/FS) redundancy on the system level during all mission phases.

The electrical and hydraulic power generation and distribution capability is comprised of the following three subsystems:

- Power generation
- Electrical power distribution
- Hydraulic power distribution

These three subsystems are discussed in detail in subsections 6.1, 6.2 and 6.3.

## 6.1 POWER GENERATION SUBSYSTEM

### 6.1.1 SUBSYSTEM REQUIREMENTS

The power generation subsystem (PGS) for the space shuttle orbiter is designed to supply the total power requirement of the orbiter in a seven day independent earth-orbital mission. The main mission phases, their time duration and average total electric power levels are given in Fig. 6.1-1. The electrical and hydraulic peak and average loads for the critical mission phases are summarized in Table 6.1-1.

TABLE 6.1-1 ORBITER POWER REQUIREMENTS

| | Boost | | Orbit | | Flyback | |
|---|---|---|---|---|---|---|
| | Peak | Avg | Peak | Avg | Peak | Avg |
| Hydraulic (hp) | 120 | 120 | 0 | 0 | 686 | 70 |
| Electrical (kw) | 42.3 | 21.4 | 11.0 | 5.3 | 9.4 | 7.8 |

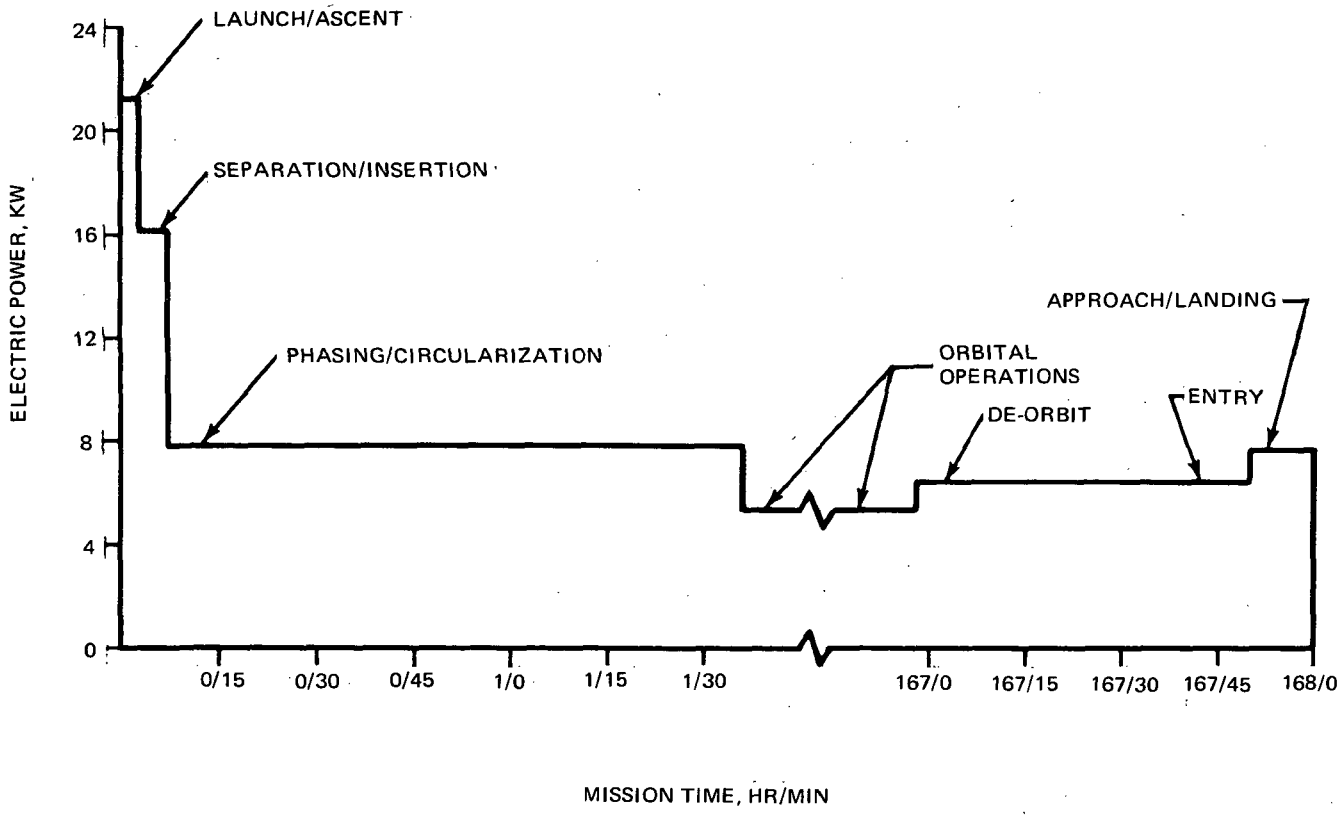


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Fig. 6.1-1 Orbiter Average Power Profile

The high electrical load requirement during orbiter boost is due to the simultaneous deployment of the three main engine nozzles.

### 6.1.2 SUBSYSTEM DESIGN

The baseline power generation subsystem configuration for the space shuttle orbiter, Fig. 6.1-2, consists of a combination of power sources, i.e., fuel cells, batteries and auxiliary power units (APU) designed to provide FO/FS redundancy for the design reference mission.

The power sources are located in two main distribution centers located in the forward and aft sections of the vehicle. The forward distribution center (FDC) contains two 7 kw $H_2 O_2$ fuel cells, two 3 kwh Ag Zn secondary batteries, two battery chargers, and associated buses, controllers and interface equipment. The aft distribution center (ADC) contains four APU-driven 15 kw brushless dc generators, four generator control units and associated distribution equipment. Power is transmitted from these main distribution centers to the subsystem utilization equipment via eight load distribution centers (LDC) located throughout the vehicle in areas of electrical load concentration. All power is generated and transmitted to the LDC's at 120 vdc. At the LDC's, the power is subjected to local power conditioning and distributed to specific loads and load groups at the required power form and power quality levels.

During normal operation, the fuel cells supply electrical power for the avionics equipment located in the forward section of the vehicle, and the dc generators supply electrical power for the main and auxiliary propulsion engines, flight control actuators, etc., located in the aft section. The batteries are used to supply peak power for the fuel cells and to provide emergency and accessory load capability.

The PGS is designed to provide FO/FS redundancy on the system level during all mission phases. Thus, in the event of the failure of both fuel cells, the avionics load is supplied by the dc generators via a cross-tie cable.

There are two candidate fuel cells for the orbiter power system: a capillary matrix type manufactured by Pratt and Whitney and a solid polymer electrolyte type manufactured by General Electric. Fig. 6.1-3 shows a functional schematic of the P&W fuel cell which is the present baseline unit.

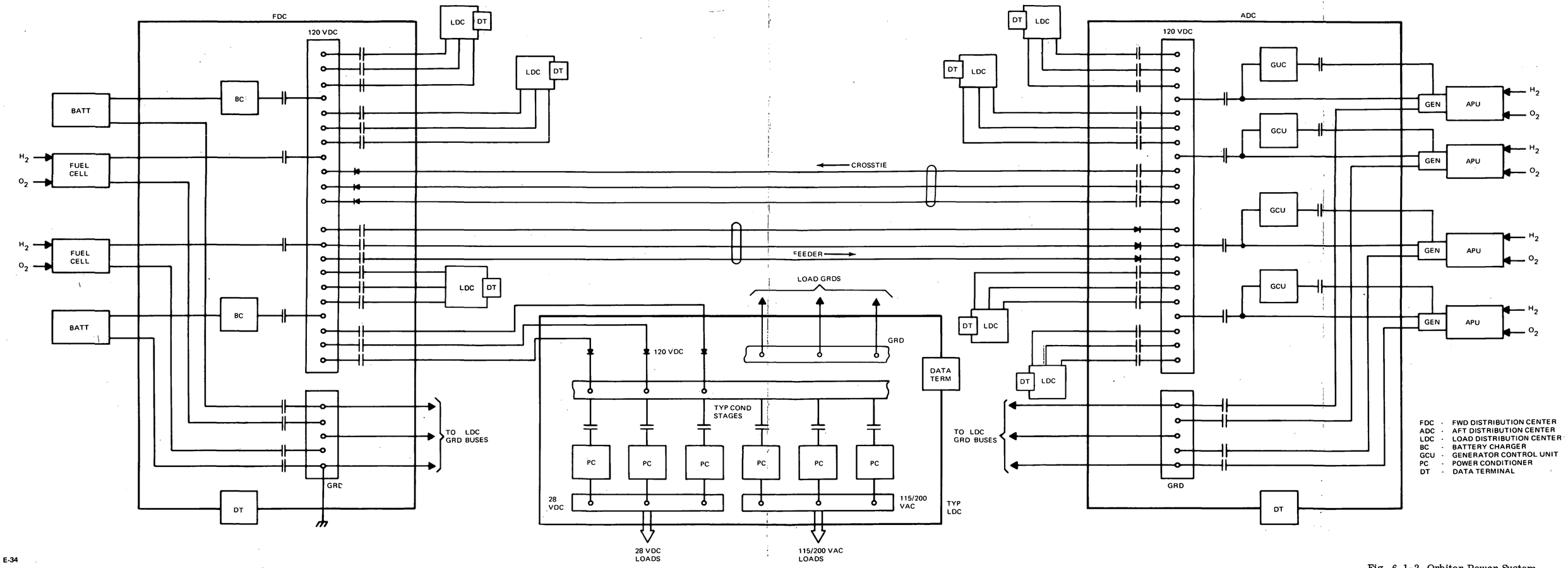




Fig. 6.1-2 Orbiter Power System



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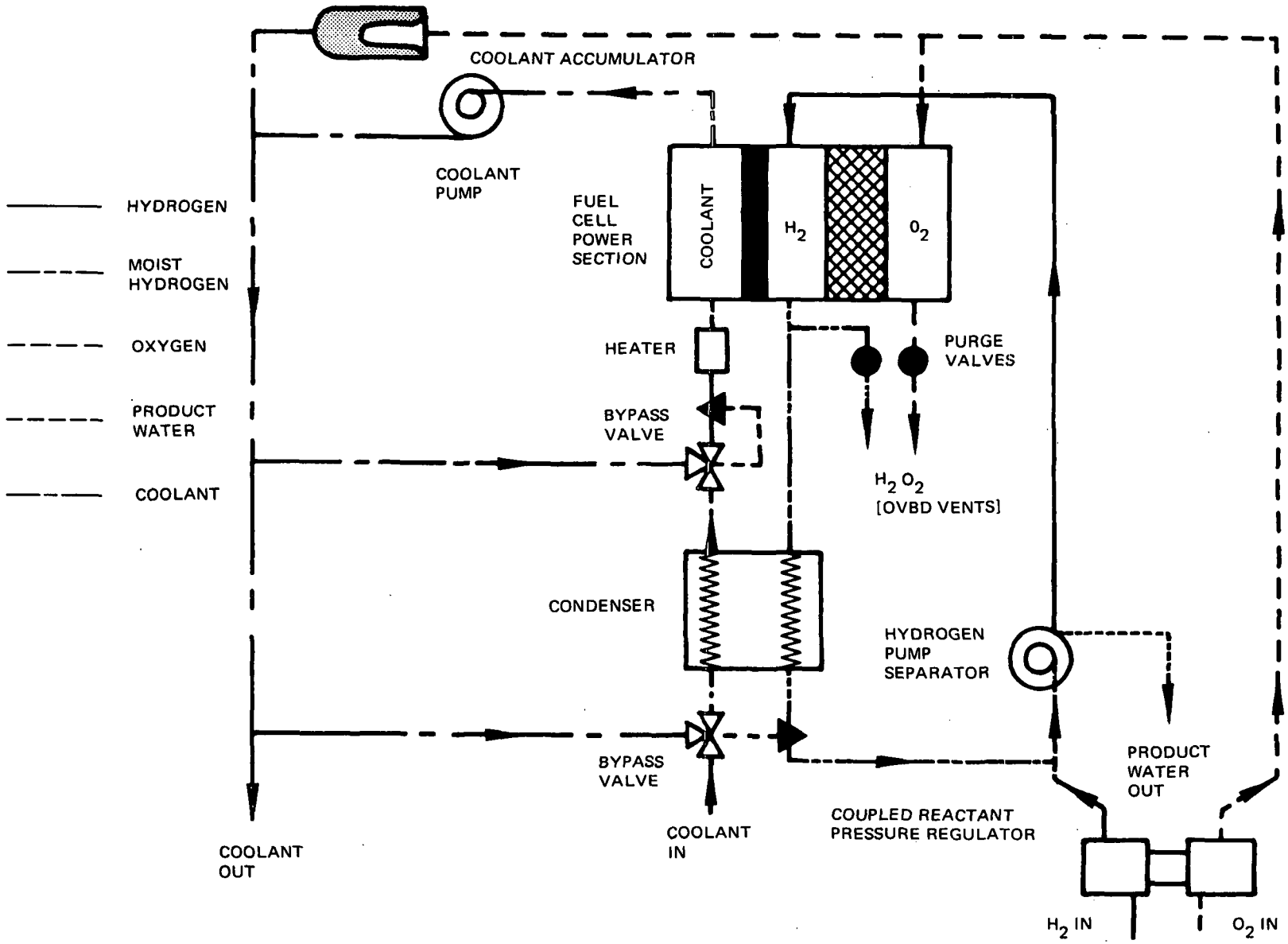


Fig. 6.1-3 Typical Fuel Cell

The APU is $H_2/O_2$ gas turbine driving two hydraulic pumps and one electric generator through a gear box. Fig. 6.1-4 shows an APU functional schematic typical of the units being developed by Rocketdyne and Airesearch under contract to Lewis Research Center for the shuttle.

A summary list of the major components in the PGS, giving their size volume, weight and power characteristics is shown in Table 6.1-3.

6.1.3 DEVELOPMENT RISKS

There is some development risk associated with all three of the major PGS components.

The fuel cell proposed is a 7 kw $H_2/O_2$ fuel cell with a specific weight of 25 lb per kw, a specific reactant comsumption of<0.9 lb per kw-hr, and a 5000 hr life. The closest existing qualified device is the Apollo Block II fuel cell which does not meet any of the stated requirements. However, the work done by Allis-Chalmers and Pratt and Whitney in developing a fuel cell for the MOL and the work currently being done by Pratt and Whitney and General Electric on development of a fuel cell for the SSV under contract to LeRC, should minimize the risk in this area.

The APU development risk is greater. There is no device currently available which meets the basic APU requirements of providing hydraulic and electric power as defined by the SSV mission profile, within the SSV environment and using $H_2/O_2$ propellants. Work is being done by Rocketdyne and Airesearch under contract to LeRC to develop such an APU. The following major development problems have been identified to date:

- Method of heat rejection - The baseline design calls for the rejection of the APU heat to the incoming $H_2$ fuel before burning it in combustion chamber. This method imposes stringent limits on the maximum temperature of the $H_2$ fuel as a function of APU power. Possible solutions to the problem are: a separate H2 accumulator tapped-off at a colder point of the ACPS, a liquid $H_2$ accumulator pumped directly from the OMS tank, or a dedicated $H_2$ tank for the APU. Other methods of rejecting the APU heat are to supplement the available ACPS $H_2$ heat rejection capacity with a water sublimation system tied into the EC/LSS

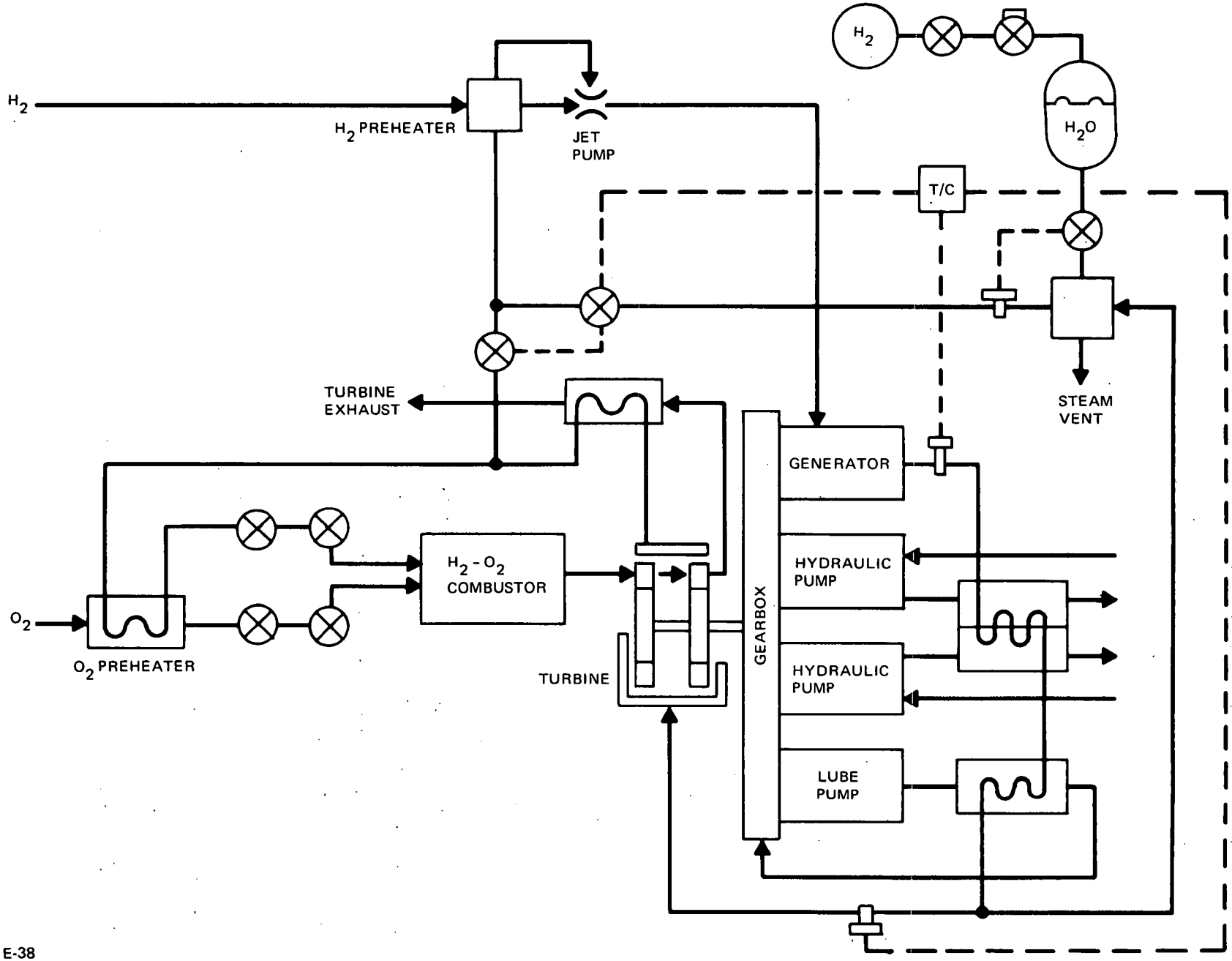


Fig. 6.1-4 Typical Auxiliary Power Unit

- Speed Control - There are two methods of power control being studied by the two main contenders; Rocketdyne uses pulsed modulation of the propellants, and Airesearch uses pressure modulation. The pressure modulation technique results in slightly better speed control than the pulsed system, however neither method may be adequate. The classical solutions to this problem are: a constant speed drive (CSD), an integrated drive generator (IDG), and a variable speed constant frequency (VSCF) system. The Grumman baseline uses 120 vdc generators rather than 115/200 vac generators, and, consequently, avoids the problem of frequency regulation which is dependent on speed regulation. This novel approach to the problem results in a simpler, lighter and cheaper PGS

The secondary battery baselined by Grumman for the PGS is a 120 vdc silver zinc (Ag Zn) battery rated at 3 kw-hr. There are risks associated with this development since there are no 120 vdc Ag Zn batteries in use today. Several 30 vdc secondary Ag Zn batteries have been built and used in earth-orbital applications, and the extrapolation of this experience to 120 vdc seems feasible. Backup positions in this area include: use of a single 30 vdc battery with a dc-dc converter, or use of a nickel-cadmium (Ni Cd) battery of either 30 vdc or 120 vdc.

### 6.1.4 VERIFICATION

The verification program for the PGS consists of two basic phases. First, the individual components will be subjected to full qualification and acceptance tests by the vendors. Second, the fuel cells and APU's will be integrated and tested as a system on a power generation subsystem integration test rig (PGS-ITR). This test rig will use gaseous $H_2$ and $O_2$ tanks with programmable supply valves to simulate transients in the ACPS and/or OMS supplies as required. The loads (electrical and hydraulic) will be simulated by programmable dummy loads to simulate mission profile requirements, and facilities will be available for thermal control. The PGS-ITR will be situated at White Sands, close to the OMS/ACPS integration test rig so that the integration of both test rigs could be considered if desired.

The battery will be integrated as part of the integrated avionics test laboratory (IATL).

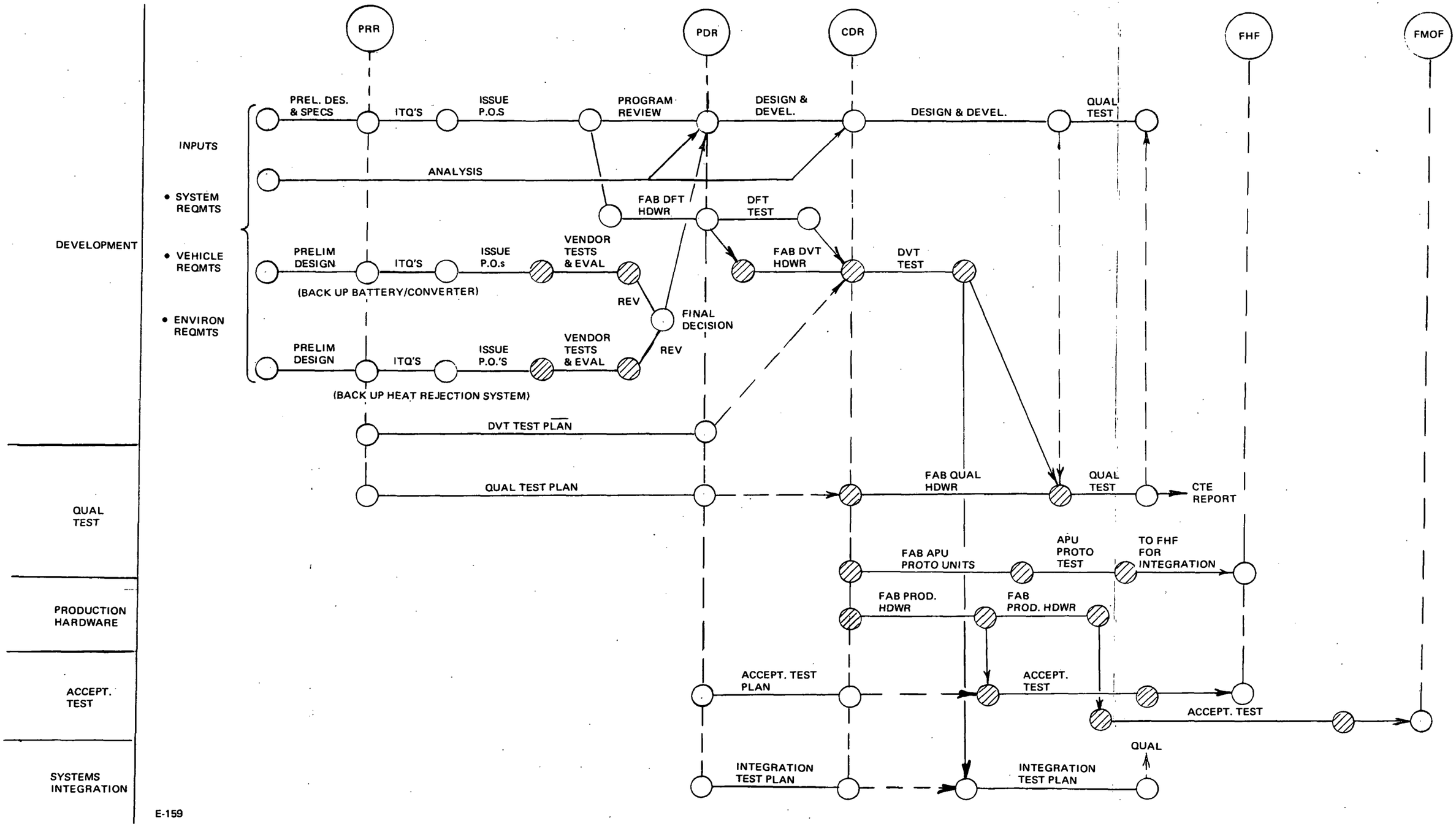


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Fig. 6.1-5 Power Generation Logic Network



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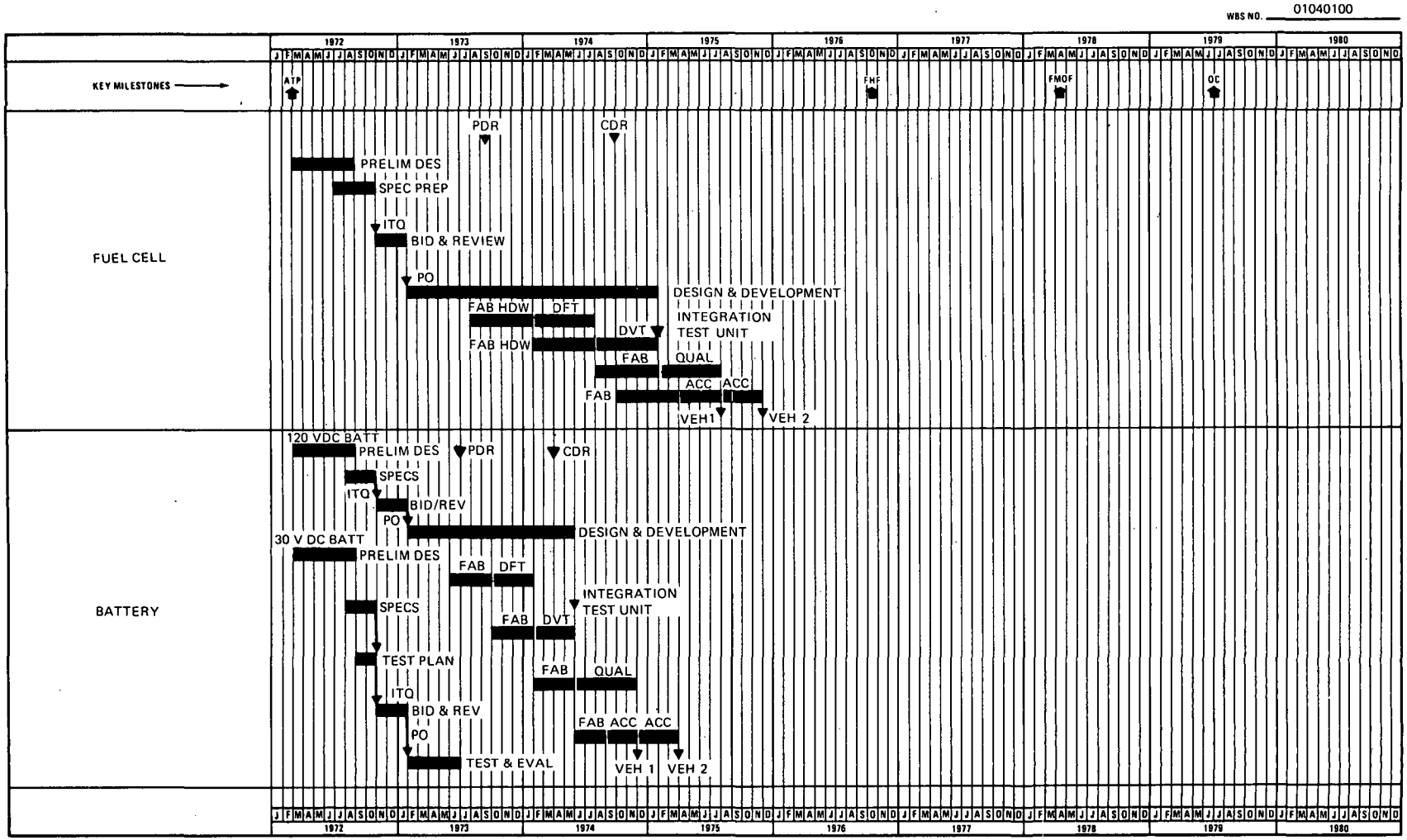


Fig. 6.1-6 Power Generation (Sheet 1 of 2)

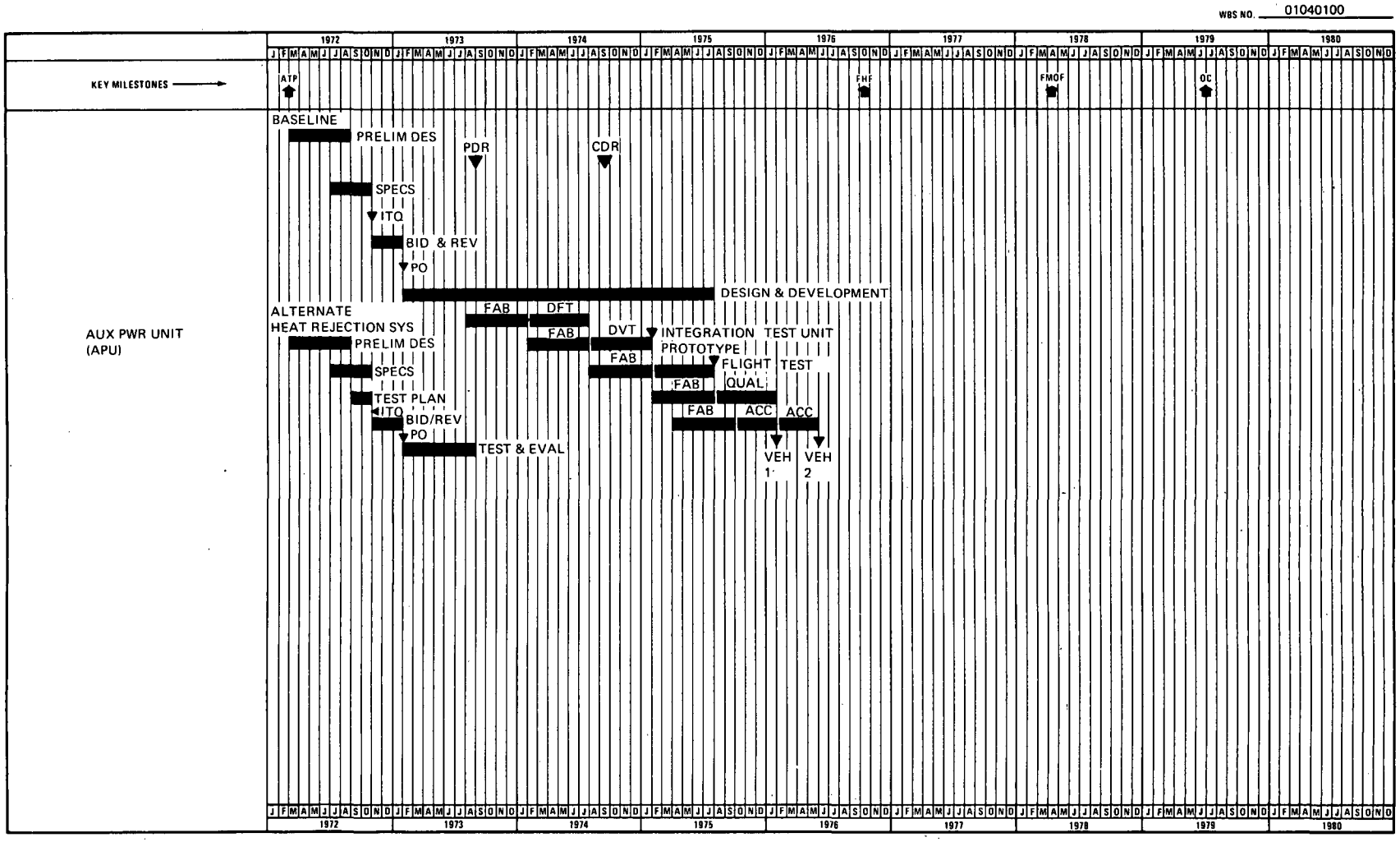


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Fig. 6.1-6 Power Generation (Sheet 2 of 2)

TABLE 6.1-2 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analysis | Simulation | Similarity | Common Usage | Test | | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| | | | | | DVT | Qual | | | | | |
| Fuel Cell | | | | | | | | | | | |
| 1. Ability to operate under continuous load & under start-stop conditions as specified | | | | | | X | | X | | | |
| 2. Ability to supply specified output power within specified voltage & current limits under load | | | | | | X | | X | | | |
| 3. Specific reactant consumption within specified value (lb/kw-hr) | | | | | | X | | | | X | |
| 4. Production of potable water under specified condition of temperature & pressure | | | | | X | | | X | | | |
| 5. Generation of heat within fuel cell under load within specified limits | | | | | X | | | X | | | |
| 6. Ability of fuel cell coolant loop to remove generated heat to EC/LSS | | | | | | X | | X | | | |
| 7. Ability of fuel cell to purge itself within specified conditions of reactant purity levels, temp & pressure | | | | | | X | | X | | | |
| 8. Compatibility of fuel cell with reactants with respect to materials, surface coating, adhesives, etc | | | | | X | | X | | | | |
| 9. Compatibility of fuel cell to vehicle with respect to structural, mounting, dimensional, volumetric & mass characteristics | | | | | X | | X | | | | |
| 10. Compatibility of fuel cell with electrical distribution subsystem with respect to cable, connector, etc | | | | | | X | | | X | | |

TABLE 6.1-2 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analysis | Simulation | Similarity | Common Usage | Test | | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| | | | | | DVT | Qual | | | | | |
| Auxiliary Power Unit (APU) | | | | | | | | | | | |
| 1. Ability to operate under continuous load & under start-stop conditions as specified | | | | | | X | | X | | | |
| 2. Ability to supply specified shaft horse-power to support system loads | | | | | | X | | X | | | |
| 3. Specific reactant consumption within specified limits (lb/hp-hr) | | | | | | X | | | | X | |
| 4. Electric generator output power within specified voltage & current limits under load | | | | | | X | | X | | | |
| 5. APU temperatures within specified limits | | | | | | X | | X | | | |
| 6. APU controls maintain specified inlet reactant temperatures, combustor temperature & turbine speed | | | | | X | | | X | | | |
| 7. Turbine wheel-burst containment | | | | | X | | | X | | | |
| 8. Satisfactory performance of APU exhaust system | | | | | X | | | X | | | |
| 9. Satisfactory performance of overheat detection system & fire isolation system | | | | | | X | | X | | | |
| 10. Compatibility of APU with reactants with respect to materials, surface coatings & adhesives, etc | | | | | X | | X | | | | |
| 11. Compatibility of APU to vehicle with respect to structural, mounting, dimensional, volumetric & mass characteristics | | | | | X | | X | | | | |

TABLE 6.1-2 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analysis | Simulation | Similarity | Common Usage | Test | | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| | | | | | DVT | Qual | | | | | |
| Auxiliary Power Unit (APU) (continued) | | | | | | | | | | | |
| 12. Compatibility of APU with electrical distribution subsystem with respect to cable, connector, etc | | | | | | X | | X | | | |
| Battery | | | | | | | | | | | |
| 1. Ability to provide specified power within specified voltage & current limits | | | | | | X | | X | | | |
| 2. Ability to accept power from Battery Charger as specified | | | | | | X | | X | | | |
| 3. Ability to operate over specified number of charge/discharge cycles | | | | | | X | | X | | | |
| 4. Generation of heat within battery over operating cycle within specified limits | | | | | | X | | X | | | |
| 5. Compatibility of battery to vehicle & to electrical distribution system | | | | | X | | X | | | | |

TABLE 6.1-3 POWER GENERATION SUBSYSTEM
MAJOR COMPONENT LIST

| Component Description | Qty Veh | Unit Volume, (cu in) | Unit Weight, (lb) | Unit Power, (watts) |
|---|---|---|---|---|
| Fuel Cell | 2 | 5760 | 175 | 7 kw |
| Aux Power Unit | 4 | 5184 | 225 | 225 hp<br>15 kw |
| Battery | 2 | 648 | 60 | 3 kwh |

TABLE 6.1-4 REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv. Units | | |
|---|---|---|---|
| | Fuel Cell | APU | Battery |
| Flight Hardware Per Vehicle | 4[a] | 1 | 4[b] |
| Component Devel & Qual Test | 2 | 1 | 2 |
| Integration Tests | | | |
| • Full Mission Simulation Laboratory | | | |
| • Integrated Avionics Test Laboratory | 1[c] | 1[c] | 1 |
| • Flight Controls Hydraulic Test Laboratory | | | |
| • Mechanical Systems Test Rigs | | | |
| • Propulsion Fluid Breadboards | | | |
| • Escape System Test Rig | | | |
| Test Articles | | | |
| • Propulsion Test Article | | | |
| • Structural Test Article | | | |
| Spares for Flight Test Program | 1 | 1 | 1 |
| Spares for 445 Flights | 2 | 1-1/2 | 2 |

a. Based on 5,000 hr life per fuel cell
b. Based on approx 25 flights per battery
c. FC/APU integration test

TABLE 6.1-5 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Design Philosophy | | | | |
| • Provide for 7 days self-sustaining mission | | | X | Not required for booster |
| • FO/FS redundancy | | X | | |
| • Primary power generation at 120 vdc | | X | | However, not very probable since booster does not use fuel cells & has a greater percentage of ac load than orbiter |
| Equipment | | | | |
| • Fuel Cell | | | X | |
| • APU | | X | | Depends on load requirements |
| • Battery | | X | | However, not likely since orbiter uses 120 vdc battery & booster would probably use a 28 vdc battery. |



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TABLE 6.1-6 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Fuel cell test stand & programmable load bank<br>• APU test stand & dummy load facility for generators & pumps<br>• Battery test stand<br>• Supporting environmental & thermal control equipment |
| Software | • Load profile simulation for $H_2/O_2$ propellant supply and fuel cell & APU test stand programmable load banks<br>• Data reduction & analysis |

TABLE 6.1-7 FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr. | Govt |
|---|---|---|---|---|
| 1. Fuel Cell/APU Integration Test Rig - (Located at White Sands)<br>• Requires gaseous $H_2$ and $O_2$ with programmable valves to simulate transients<br>• Requires programmable dummy electrical and hydraulic load banks<br>• Requires all necessary instrumentation and data recording equipment<br>• Floor space 60 x 80 ft<br>• All $H_2$, $O_2$ and electrical safety codes | X | | | |
| 2. Battery Test Rig - Part of integrated avionics test stand (IATL). Requirements TBD | X | | | |

TABLE 6.1-8 COMPUTER DESIGN SUPPORT REQUIREMENTS

1. Load Analysis Program - Required to analyze effects of changing loads on system

   Estimate: 64 minutes per year machine time (main frame)

2. System Analysis Program - Required to analyze interaction of fuel cells, APU generators, and batteries under dynamic system conditions

   Estimate: 600 minutes per year machine time (main frame)

# 6.2 ELECTRICAL POWER DISTRIBUTION SUBSYSTEM

## 6.2.1 SUBSYSTEM REQUIREMENTS

The baseline electrical power system for the space shuttle orbiter consists of a power generation subsystem, described in subsection 6.1, and an electrical power distribution subsystem (EPDS) which includes the functions of distribution, conditioning and control of electrical power. The EPDS is required to provide adequate amounts of properly conditioned power to the vehicle utilization equipments with FO/FS redundancy over the mission timeline.

## 6.2.2 SUBSYSTEM DESIGN

The electrical power distribution subsystem configuration is shown schematically in Fig. 6.2-1. The design utilizes the concepts of solid state power management (SSPM) and standardized modular power conditioning (SMPC).

The power sources are located in the forward and aft distribution centers, (FDC) and (ADC), respectively. Power is transmitted from these centers to the subsystem utilization equipments via eight load distribution centers (LDC) located throughout the vehicle in areas of electrical load concentration. All power is generated and transmitted to the LDC's at 120 vdc. At the LDC's, the power is subjected to local power conditioning, and distributed to specific loads and load groups at the required power form and power quality levels.

The use of dc voltage for power transmission requires a minimum number of power and signal lines, control elements, distribution components, and power and signal interfaces, and results in a system which is relatively simple and very reliable.

In addition, the dc power form permits complete isolation of redundant power lines from each other by means of isolating diodes. Power is transmitted from one point to another using only three pairs of wires, positive and negative, for FO/FS redundancy. In general, the isolating diodes are located at the load terminals with solid state power controllers at the source terminals to provide control.

The specific use of 120 vdc is based on the projected availability of a fuel cell with 120 vdc output. Although the use of a higher voltage would reduce the size and weight of the distribution lines and components, it would require a dc-dc conversion stage at the output of the fuel cells which would detract from the distribution weight saving and increase the overall system complexity.

Control of the power system is effected by means of solid state power controllers located in the distribution centers. The use of SSPM results in significant improvements over conventional electromechanical devices in size, weight, performance and reliability since all moving contacts, control logic and circuit protection functions are performed by solid state devices. SSPM is also more compatible with multiplexed data bus systems than the conventional electromechanical approach.

Under normal operating conditions, all the bus controllers which connect the power sources to the main distribution buses and all the feeder controllers, which connect the main distribution buses to the LDC feeders, are closed. The cross tie controllers are open unless required to provide electrical power forward in the event of loss of both fuel cells. The power controllers in the local distribution centers, which connect the power conditioners, are closed and the power controllers which control the individual loads and load groups are open or closed as required.

Each power controller is controlled via the data bus on the basis of voltage and current measurements or mission timeline requirements. The power system is continuously monitored and automatically reconfigured by the data management system via the data bus. Manual override or intervention is available on demand.

All power conditioning functions are performed within the distribution centers through the use of standardized modular power conditioning (SMPC) modules. Figure 6.2-2 shows some typical SMPC designs. The SMPC approach uses state-of-the-art circuit designs with common conditioning functions broken down into function modules such that many different conditioning designs can be derived from a basic set of standardized function modules. This approach offers a high degree of flexibility, ease of maintenance, and minimum logistics requirements.

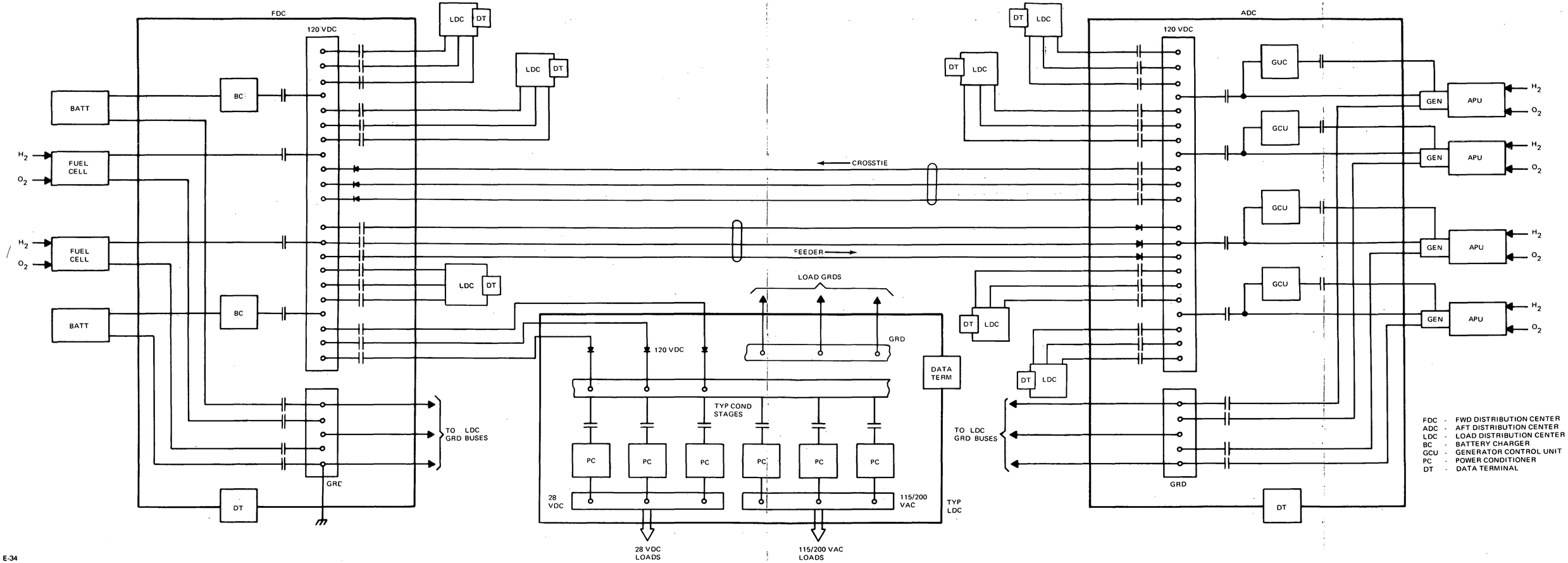


Fig. 6.2-1 Orbiter Power System



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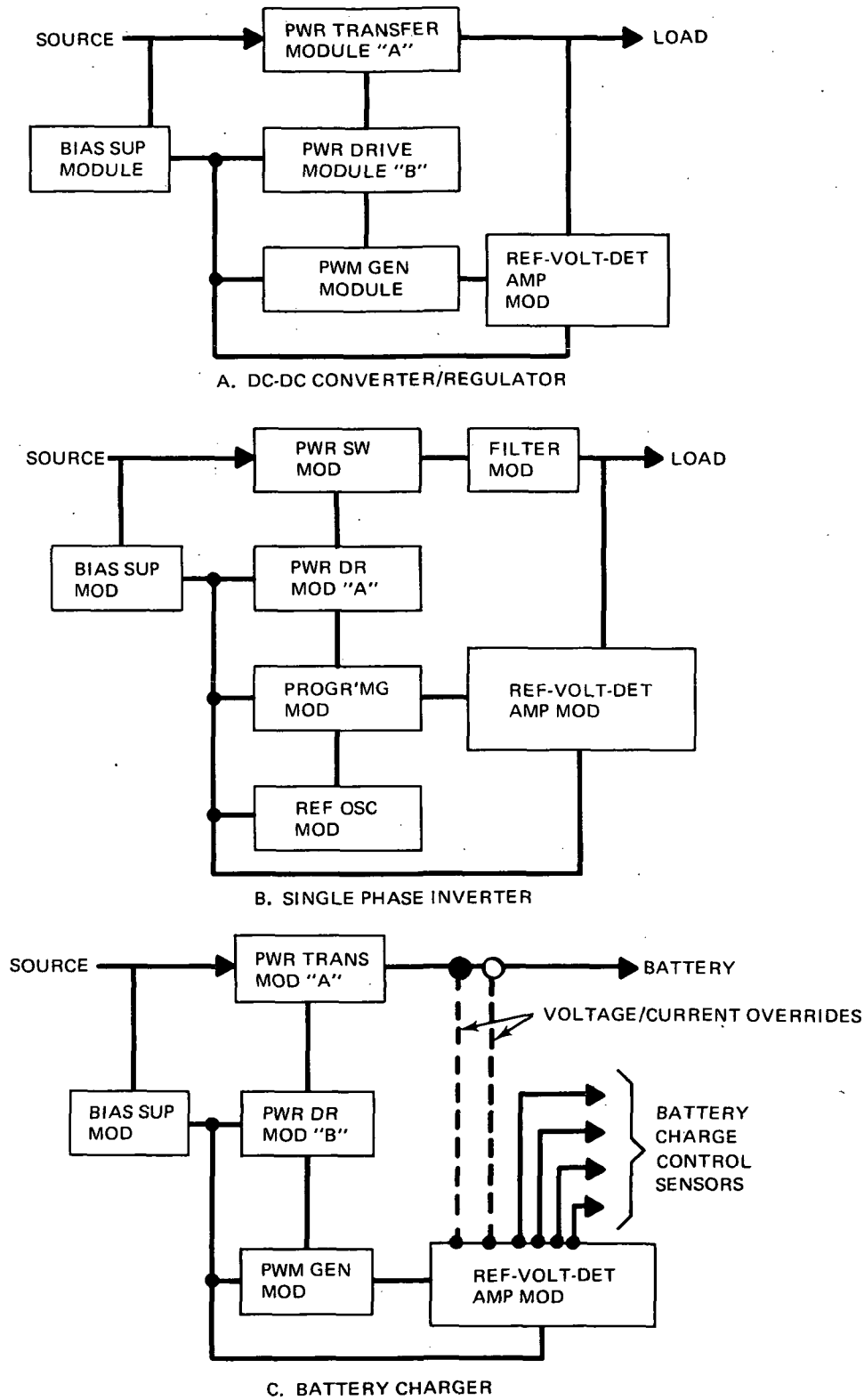


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Fig. 6.2-2 Typical SMPC Power Conditioner Designs

A summary list of the major components in the EPDS, giving their size, volume, weight and power characteristics, is shown in Table 6.2-2.

### 6.2.3 DEVELOPMENT RISKS

There are no serious risks in the EPDS; however, there are some areas which require development effort. In the area of the solid state power controller, devices have been developed with ratings up to 35 amperes at 30 vdc and 35 amperes at 115/200 vac. Although these current ratings are more than adequate for the Grumman design, the dc voltage rating of 30 vdc is not compatible with the 120 vdc transmission voltage design. The risk associated with the development of a 120 vdc solid state power controller is not great since the basic technology and the components required are entirely within the present state-of-the-art and, for the most part, commercially available. Several manufacturers have started work on the 120 vdc solid state power controller and the NASA LeRC has recently issued an RFP for a study program on such a device.

In the area of power conditioning, the circuitry proposed is all state-of-the-art. The only innovation is in the packaging to obtain the "standardized modular" hardware. The risk in this area is minimal.

### 6.2.4 VERIFICATION

The proposed method of verification consists of two phases: first, qualification and acceptance testing by the manufacturer, and second, a system integration test on the integrated avionics test laboratory (IATL).

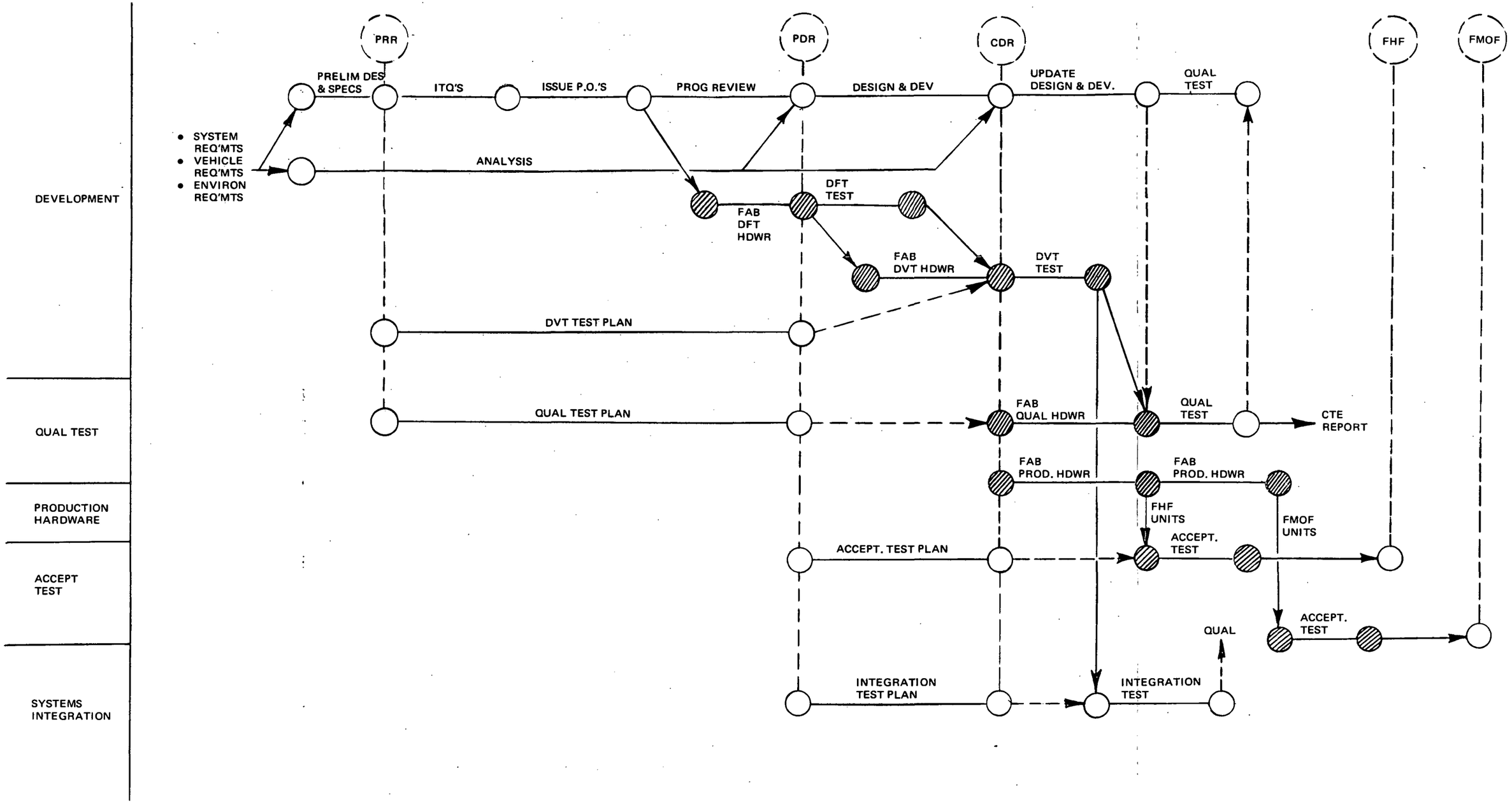


Fig. 6.2-3 Electrical Power Distribution Logic Network



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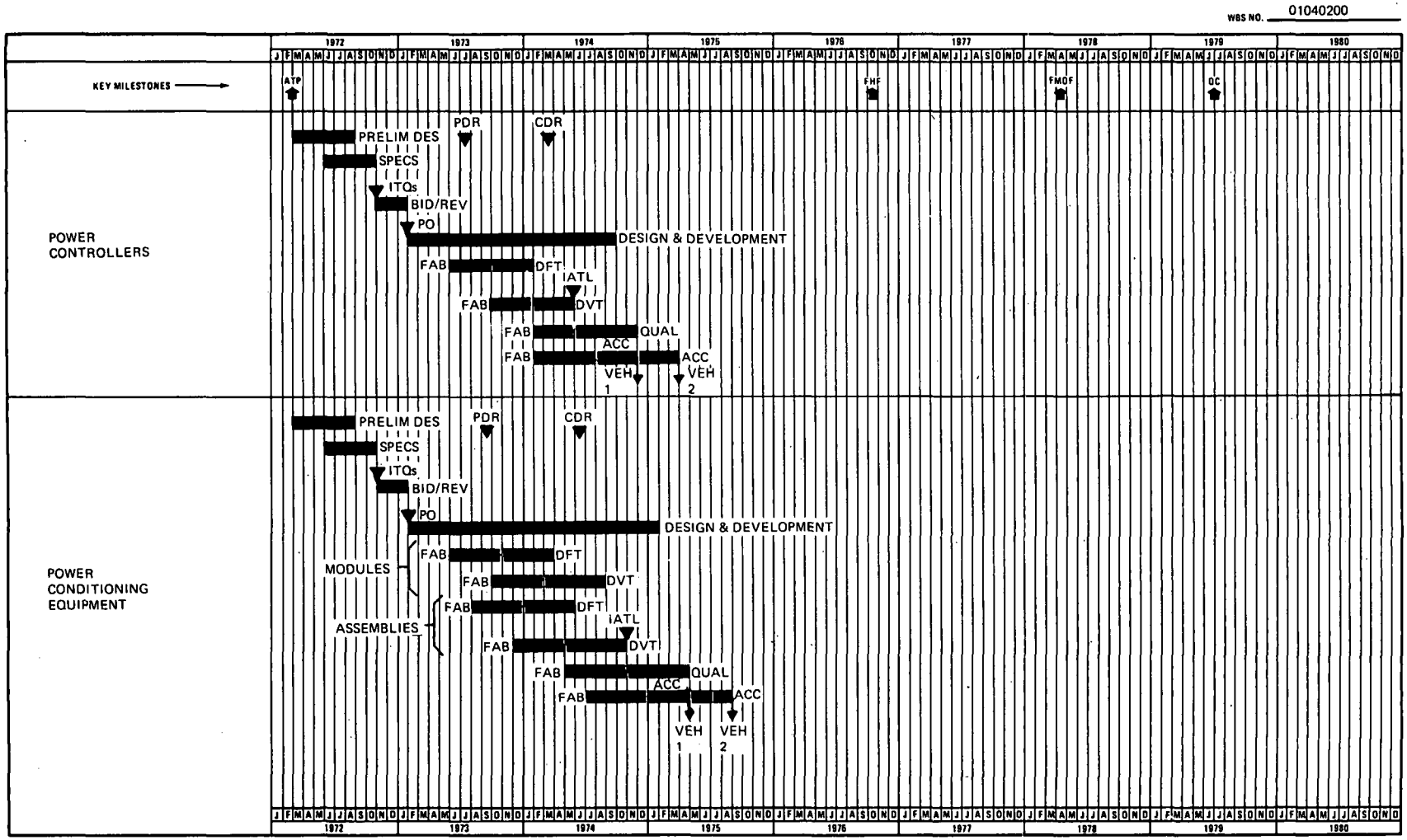



Fig. 6.2-4 Electrical Power Distribution

TABLE 6.2-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 2)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| 1) Ability of EPDS to provide specified power within specified voltage, current, frequency & power quality characteristics under both steady state & transient load conditions | | | | | | X | | | | X | |
| 2) Ability of EPDS to operate from simulated GSE & space station external sources | | | | | | X | | | | X | |
| 3) Performance of redundancy management & automatic fault isolation under simulated fault conditions | | | | | X | | | | X | | |
| 4) Performance of subsystem with data management subsystem with respect to data acquisition & command response | | | | | X | | | | | X | |
| 5) Compatibility of all interconnections in subsystem, i.e. harnesses, buses, connectors, junction boxes, external power inputs, etc | | | | | | X | | | | | X |
| 6) Compatibility of all power control & conditioning assemblies with structure, cold rails, mounting substructure, etc | | | | | | X | | | | | X |
| 7) Grounding, bonding, insulation, isolation, EMI, shock hazard & safety checks | | | | | | X | | | | | X |
| 8) Accessibility, proper mechanical operation, & maintainability checks | | | | | X | | | | | | X |

TABLE 6.2-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 2)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| 9) Proper operation of generator control unit (GCU) battery charger & fuel cell interface with EPDS | | | | | X | | | | | X | |
| 10) Vehicle integration:<br>structural<br>thermal<br>mechanical<br>environmental | | | | | | X | | | | | X |

TABLE 6.2-2 ELECTRICAL POWER DISTRIBUTION, CONDITIONING & CONTROL SUBSYSTEM MAJOR COMPONENT LIST

| Component Description | Qty/ Veh | Total Volume, cu in. | Total Weight, lb | Total Power Type Watts |
|---|---|---|---|---|
| Main Distribution Center-Forward | 1 | 2448 | 122 | DC-7 kw |
| Main Distribution Center-Aft | 1 | 2160 | 108 | DC-7 kw |
| Local Distribution Center (A) | 4 | 8880 | 480 | DC-6 kw<br>AC-2 kw |
| Local Distribution Center (B) | 4 | 2208 | 120 | DC-2 kw<br>AC-1 kw |
| Total | | 15,695 | 830 | |

Notes:
a. Equipment size, weight and power figures do not include allowance for main structure, cold rails, and data bus interface units (RACU)

b. Electrical wiring, junction boxes and other distribution hardware are summarized in subsection 5.6, Electronic Subsystem Integration

TABLE 6.2-3 REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv. Units |
|---|---|
| Flight Hardware per Vehicle | 1 |
| Component Devel. & Qual. Test | 1-1/2 |
| Integration Tests | |
| • Full Mission Simulation Laboratory | |
| • Integrated Avionics Test Laboratory | 1 |
| • Flight Controls Hydraulic Test Laboratory | |
| • Mechanical Systems Test Rigs | |
| • Propulsion Fluid Breadboards | |
| • Escape System Test Rig | |
| Test Articles | |
| • Propulsion Test Article | |
| • Structural Test Article | |
| Spares for Flight Test Program | 1 |
| Spares for 445 Flights | 2 |

TABLE 6.2-4 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Design Philosophy | | | | |
| • 120 vdc Generation & Transmission of Power | | X | | Not probable since booster does not use fuel cells and has greater percentage of ac loads |
| • FO/FS System Redundancy | | X | | |
| • Solid State Power Management (SSPM) | | X | | Different types and ratings - Some common |
| • Standardized Modular Power Conditioning (SMPC) | | X | | Different conditioning requirements for booster - Some common |
| Equipment | | | | |
| • Power Controllers | | X | | See above |
| • Power Conditioners | | X | | See above |

TABLE 6.2-5 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Integrated Avionics Test Laboratory (IATL)<br>• Programmable Power Supplies<br>• Programmable Load Banks<br>• Instrumentation |
| Software | • System Performance Simulation Program<br>• Data Reduction and Analysis |

TABLE 6.2-6 FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr. | Govt |
|---|---|---|---|---|
| • Integrated Avionics Test Laboratory will be used by EPDS | X | | | |

TABLE 6.2-7 COMPUTER DESIGN SUPPORT REQUIREMENTS

The computer support requirements described and defined in paragraph 6.1.8 are shared between power generation and electrical power distribution - i.e., the same programs are used by both.

# 6.3 HYDRAULIC POWER SUBSYSTEM

## 6.3.1 SUBSYSTEM DESCRIPTION

The hydraulic power subsystem (Fig. 6.3-1) is comprised of four completely independent systems, each powered by one of four APU's developing 3000 psi system pressure. All four systems supply hydraulic power to the primary flight control system, consisting of the flight control surfaces (elevons, rudders, aerodynamic speed brakes) and main rocket engine gimbaling actuation. Two of the four systems also supply hydraulic power to the utility system consisting of main landing gear actuation (including locks and closure doors), the nose gear functions of extend, retract and steering, wheel brakes, anti-skid, and air-breathing engine deployment (including locks and closure doors). Emergency extension of door/nose gear are achieved by a stored energy system. Priority valves ensure preference of hydraulic power to the flight control system in event of malfunction or failure of utilities branch equipment. A temperature conditioning system uses electric pumps in each of the four systems to provide sufficient flow during inactive or shut-down periods to maintain fluid within thermal operating limits.

Hardware selection follows the latest aircraft state-of-the-art concepts modified as required for the shuttle mission use. A list of the major components is given in Table 6.3-1. Hydraulic system components requiring periodic replacement, maintenance and/or inspection will be installed in the main gear compartment where possible and in the nose wheel well for the nose gear system.

## 6.3.2 POTENTIAL DEVELOPMENT PROBLEM AREAS

High-temperature requirements, as well as exposure to a space environment, necessitates an advancement in the state-of-the-art of hydraulic fluid and seals. Although considerable developmental work has been accomplished in both of these areas, additional effort is required before either are considered operational. Significant work is in progress

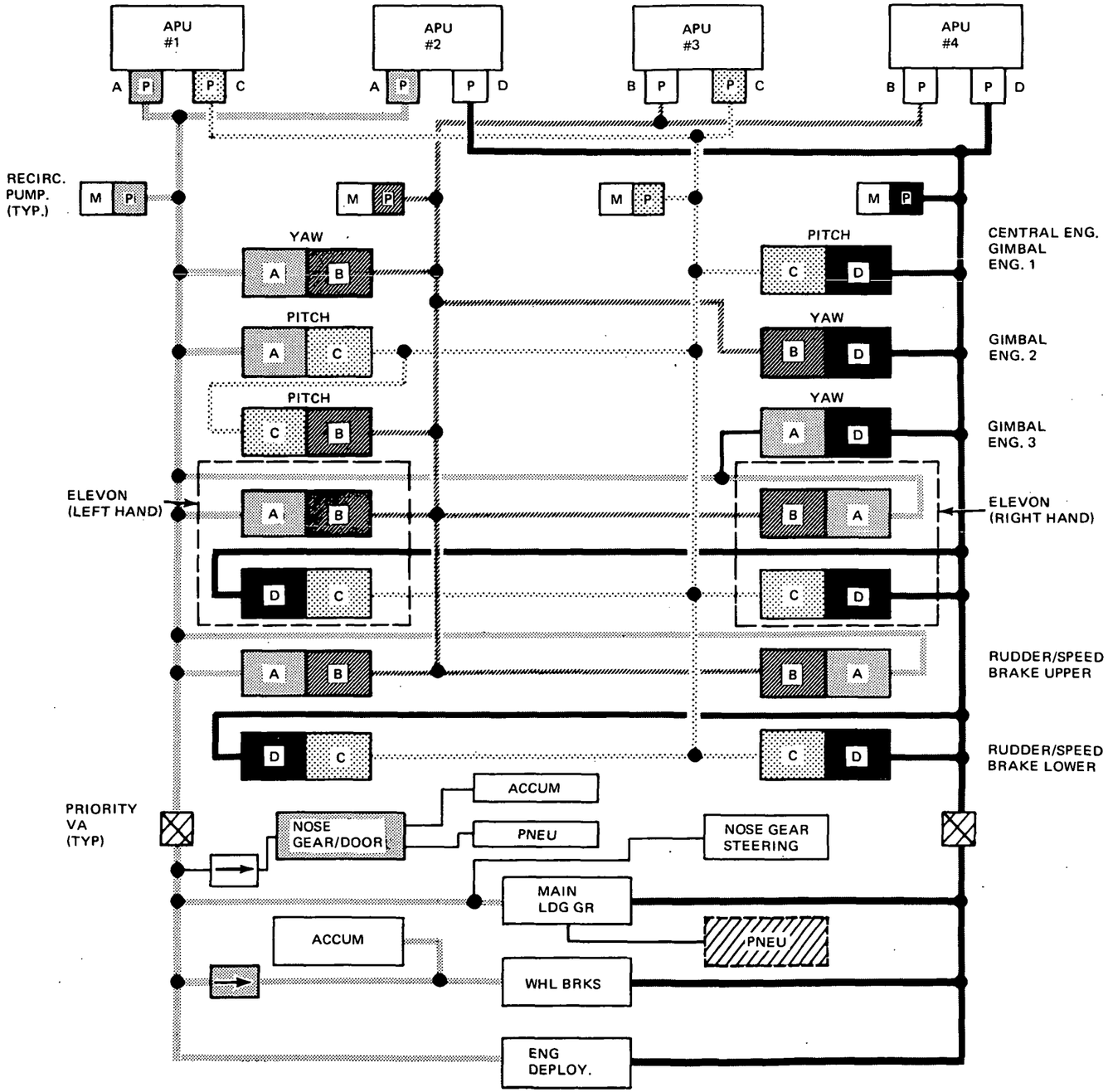
on both fluids and seals by NASA-Lewis. In addition, Grumman has been pursuing an in-house high-temperature hydraulic system program that includes the evaluation of fluids, seals and pump and accumulator materials.

Simulator testing of a complete, full-scale hydraulic system integrated with flight controls will make it possible to expose any detrimental interaction between the various subsystems, and permit corrective action prior to flight.

The thermal environment is expected to produce problems for the hydraulic power system. The high temperatures during reentry and the low temperatures during orbital periods require a conditioning system not normally encountered in aircraft hydraulics design. A problem exists in providing actuators with a cooling flow that can be maintained during the reentry period when the actuator is not being operated. An example of this would be the engine deployment actuators which are not used until the vehicle is down to 30,000 feet.

A similar but opposite problem exists during the orbital period when the hydraulic systems are inactive and will cold soak. Although a circulating pump is incorporated in each system to maintain a warming flow, some doubt exists as to whether this flow can reach the end of a large inactive actuator. Under consideration presently is the use of electric heating blankets plus thermal protection. The thermal blanket would prevent loss of heat during the orbital phase and, acting as an insulator, would exclude heat during the reentry phase.

Another problem occurring during reentry is that of actively cooling and maintaining lubricity of a piston rod that has been in an extended position in a hot environment. Although it is possible to design the rod with internal cooling passages, the dry surface resulting from the environment could cause seal damage during retraction. Studies are now under way at Grumman to encapsulate the piston rod with a metallic bellows containing a cooling and lubricating flow of hydraulic oil. Development and verification testing of the power and recirculating pump systems will be performed under worst case duty cycle load conditions combined with the appropriate extremes of high and low temperatures. All certification requirements are summarized in the tables.

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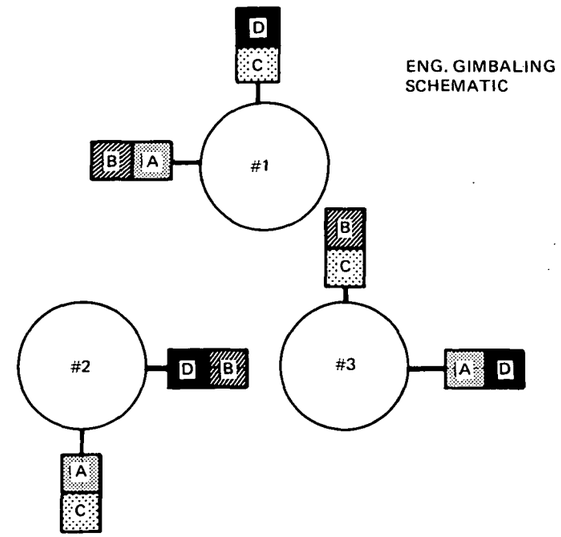


Fig. 6.3-1 Orbiter Hydraulic Schematic



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## 6.3.3 HYDRAULIC POWER EQUIPMENT DATA

Hydraulic power equipment data is given in Tables 6.3-1 through 6.3-6.

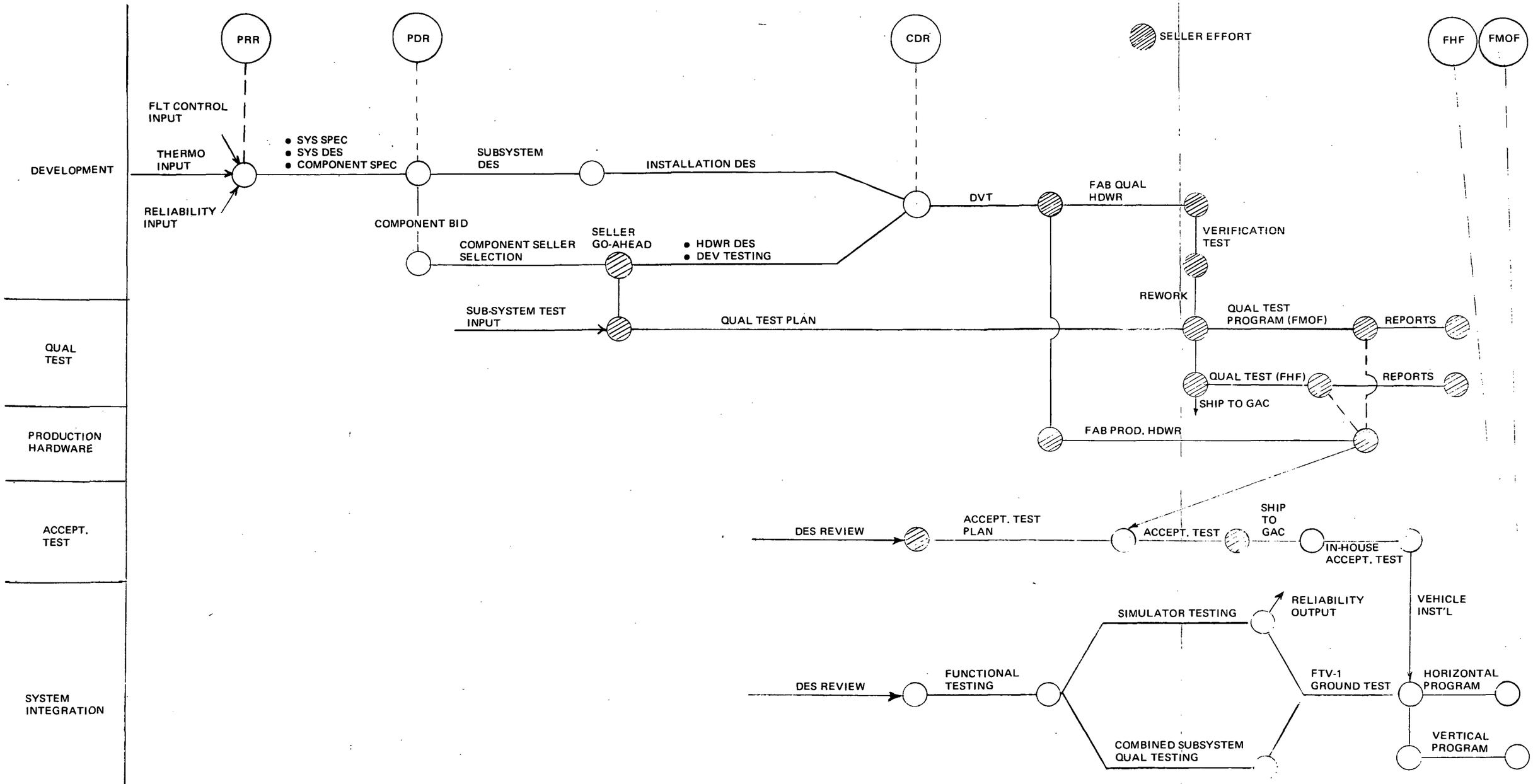


Fig. 6.3-2 Hydraulic Power Logic Network



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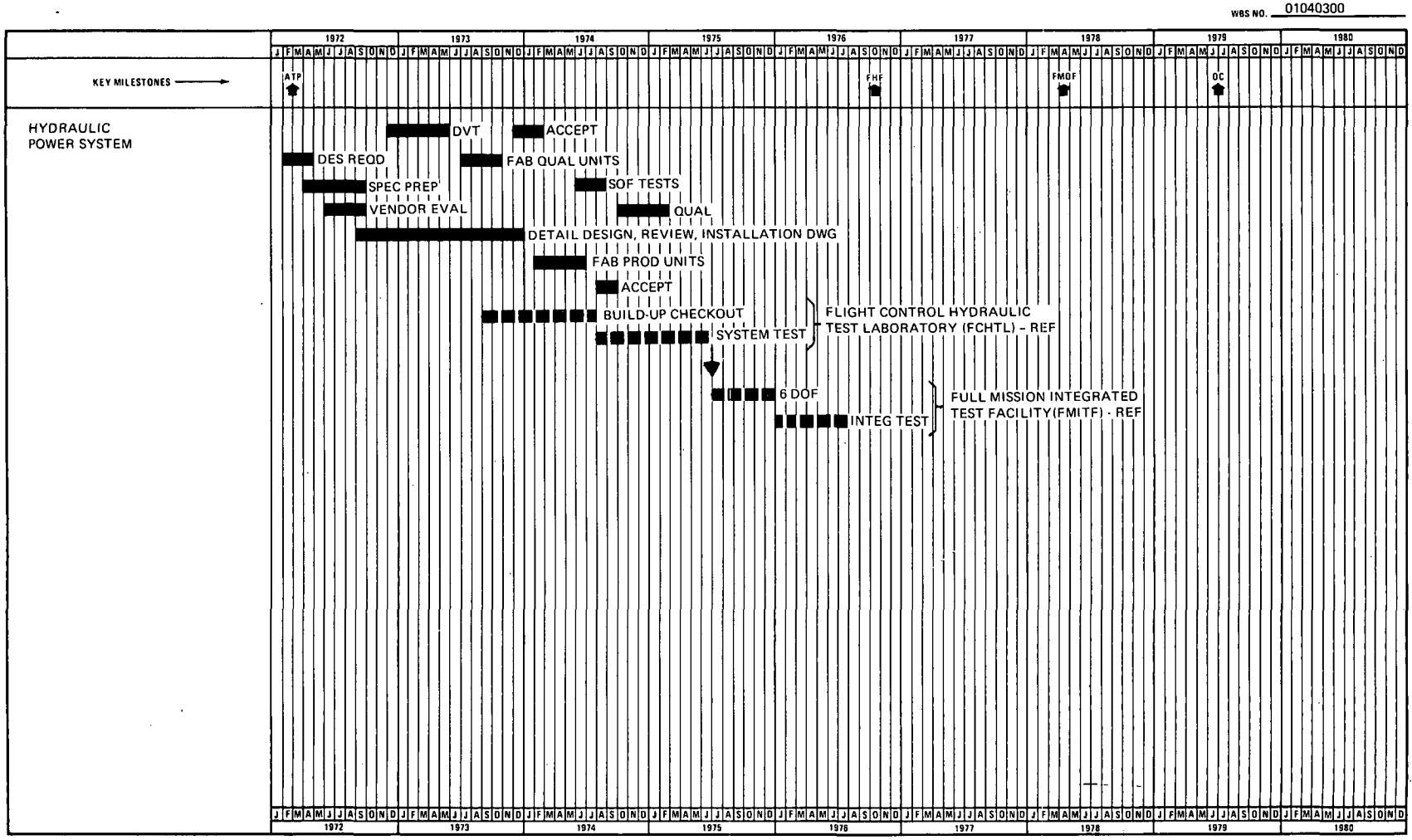


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Fig. 6.3-3 Hydraulic Power



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TABLE 6.3-1 HYDRAULIC CERTIFICATION REQUIREMENTS (Sheet 1 of 2)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | QUAL | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Hydraulic Power Generating System | | | | | | | | | | | |
| • Pressure Generating and Regulation Capability | | | | | | X | | X | | | |
| • Flow Regulation | | | | | X | | X | | | | |
| • Response Capability | | | | | | X | X | | | | |
| • Leakage Requirements | | | | | | | | | | | |
| - Internal | | | | | | X | X | | | | |
| - External | | | | | | X | X | | | | |
| • Endurance - Typical Flight Profile Cycling | | | | | | X | | X | | | |
| • Thermal Generation Heat Rejection | X | | | | X | | X | | | | |
| • Vibration Susceptibility Over Operating Regime | | | | | X | | | | | | |
| • Reliability | | | | | | | | X | | | |
| • Proof and Burst Requirements | X | | | | X | | X | | | | |
| Pressurization Systems (Pneumatic and/or Cryo) | | | | | | | | | | | |
| • Response | | | | | X | | X | | | | |
| • Regulation | | | | | X | | X | | | | |
| • Leakage | | | | | X | | X | | | | |
| • Stiffness | | | | | X | | X | | | | |
| • Dynamics | X | | | | X | | | | X | | |
| • Reliability | X | | | | | | | | X | | |

TABLE 6.3-1 HYDRAULIC CERTIFICATION REQUIREMENTS (Sheet 2 of 2)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | QUAL | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Pressurization Systems (Pneumatic and/or Cryo) | | | | | | | | | | | |
| • Fail Safe Operation | X | | | | X | | | | X | | |
| • Integration Compatibility | | | | | X | | | | | | X |
| Door Actuators | | | | | | | | | | | |
| • Proof pressure tests | | | | | | X | X | | | | |
| • Response | | | | | X | | X | | | | |
| • Leakage | | | | | X | | X | | | | |
| • Sequencing | | | | | | X | | | | X | |
| • Fluid Temperature Range | | | | | X | | X | | | | |
| • Override Capability | | | | | | X | | | X | | |
| • Thermal Environment | | | | | | X | | | X | | |
| • Interface Compatibility | | | | | X | | | | X | | |
| • Space Environment Capability | | | | | | X | X | | | | |
| • Redundancy | | | | | X | | X | | | | |
| • Endurance | | | | | | X | X | | | | |
| • Burst | | | | | | X | X | | | | |

TABLE 6.3-2 HYDRAULICS MAJOR COMPONENT LIST

| Comp. No. | Description | Qty/ Vehicle | Wt (Each), lb | Size (Each), cu ft | Hp (Each) |
|---|---|---|---|---|---|
| 1 | Pumps (APU driven) | 4 | 25 | 1.0 | 100 |
| 2 | Pumps (Elec Motor Driven, Circul) | 4 | 30 | 0.42 | 1.5 |
| 3 | Boot Strap Reservoir | 4 | 90 | 2.4 | NA |
| 4 | Heat Exchangers | 4 | 147 | TBD | NA |

TABLE 6.3-3 HYDRAULIC REQUIRED EQUIVALENT UNITS

| Description | Required Equiv Units |
|---|---|
| Flight Hardware Per Vehicle | 1 |
| Component Development & Qual Test | 3 |
| Integration Tests | |
| • Full Mission Simulation Lab | |
| • Integrated Avionics Test Lab | |
| • Flight Controls Hydraulic Test Lab | 1.5 |
| • Mechanical Systems Test Rigs | 1 |
| • Propulsion Fluid Breadboards | |
| • Escape System Test Rig | |
| Test Articles | |
| • Propulsion Test Article | |
| • Structural Test Article | |
| Spares For Flight Test Program | 1.5 |
| Spares For 445 Flights | 4.0 |

TABLE 6.3-4 HYDRAULICS BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| | Item | Common | Potential Common | Not Common |
|---|---|---|---|---|
| 1 | Pumps (APU Driven) | | | X |
| 2 | Pumps (Elec Motor Driven, Circul) | | | X |
| 3 | Boot Strap Reservoir | | | X |
| 4 | Filters | X | | |
| 5 | Selector Valves | | X* | |
| 6 | Accumulators | X | | |
| 7 | Modules | | X* | |

*Detailed system analysis required to determine possible commonality

TABLE 6.3-5 HYDRAULIC SUPPORT EQUIPMENT

| Item | Requirements |
|---|---|
| Support Equipment | • Vacuum pump<br>• Electric motor driven variable speed drives for pumps<br>• Ground Hydraulic Power Unit<br>• Programmable loads for simulating elevons, rudder, gimbals, utility actuators<br>• Test gas distribution/regulation unit<br>• Test control console<br>• Electrical ground power and distribution test equipment<br>• High and low temperature<br>• Data acquisition |

TABLE 6.3-6 HYDRAULIC FACILITY
REQUIREMENTS LIST

| Facility | New | Exist'g | Contr | Gov |
|---|---|---|---|---|
| • Component Qualification Test facilities (Seller) | | X | X | |
| • Hydraulic Subsystem Test Facility - Hi-Lo Temp Chamber (15 Ft x 5 Ft x 5 Ft, 440V, 220V, 28VDC, $H_2O$, $N_2$, drain) | X | | X | |

No Computer Support Required

Section 7

# ENVIRONMENTAL CONTROL/LIFE SUPPORT

Environmental control provides crew life support functions and active temperature control for the shuttle vehicle and vehicle subsystems as required. It consist of the following sections:

- Atmospheric revitalization section (ARS)
- Heat transport/heat rejection section (HTS/HRS)
- Atmospheric supply and composition control (ASCCS)
- Water and food management section (WFMS)
- Waste management section (WMS)

Detailed schematics, descriptions, and functions are given in the Technical Summary. With the exception of the ARS and the number of radiator panels used, the subsystem is sized to support maximum crew sizes of 14 men. The ARS is sized for the baseline four-man crew. For larger crew sizes, modularized ARS packages would be added and additional radiator panels would be provided. For missions longer than the baseline 7 days, additional nitrogen storage would be provided in the ASCCS and an increased capacity fecal storage unit would be incorporated. The interrelation between the sections and major elements are shown schematically in Fig. 7-1.

## 7.1 GENERAL DEVELOPMENT PHILOSOPHY

The EC/LS subsystem will be basically a purchased system whose components are developed and verified by subcontractors who are specialists in manufacturing this type of hardware. Areas designed and manufactured in-house will be the cold rails and radiators in addition to all ducting and piping. Our effort will be one of design specification and control with detailed monitoring of the vendor effort through all phases of design development, manufacturing, and test verification. A major portion of our development task will be to integrate the EC/LS sections into a working unit compatible with the vehicle systems and

missions. The integrated test philosophy is outlined in a later section and will be the method employed to verify all section compatibility.

The following paragraphs briefly highlight the anticipated development problems for the baseline system described in the Technical Summary.

### 7.1.1 ATMOSPHERIC REVITALIZATION SECTION

The development of this section baseline design will be straightforward with no technology breakthrough required. Both major functions of the ARS ($CO_2$ removal and humidity control) are accomplished with technology developed and proven on LM. Humidity control is by condensing heat exchanger and water separators and $CO_2$ removal is by LiOH absorbtion. The development task, therefore, reduces to one of design optimization and correction of minor faults in the LM system design.

### 7.1.2 HEAT TRANSPORT AND HEAT REJECTION SECTION

This section development will envolve an internal water heat transport loop and an external Freon 21 radiator loop.

The water circuit is similar to the LM glycol loop, and this experience will preclude basic design faults before they occur. The use of water in the EOS system will eliminate the inhibitor depletion and precipitation problem which was a major operational constraint on LM. Other areas causing difficulty on LM involved leakage of mechanical joints swaged to thin-wall aluminum tubing and excessive servicing time to fill and drain the loop. The EOS requirement for repeated long-term usage with minimum turnaround time dictates a system with the least number of mechanical joints and possible stainless steel lines to eliminate corrosion and frequent servicing. Throughout the design phase, considerable attention will be given to reducing servicing time by minimizing the number of fluid traps and, if necessary, incorporation of low point drains or multiple servicing ports. Experience gained on LM will also result in easier cold rail development and manufacture since Grumman was the innovator of this concept. The individual components of this section (except cold rails) will be developed and verification-tested by a vendor. Integration of these individual components will be done in-house as outlined in the test program paragraph.

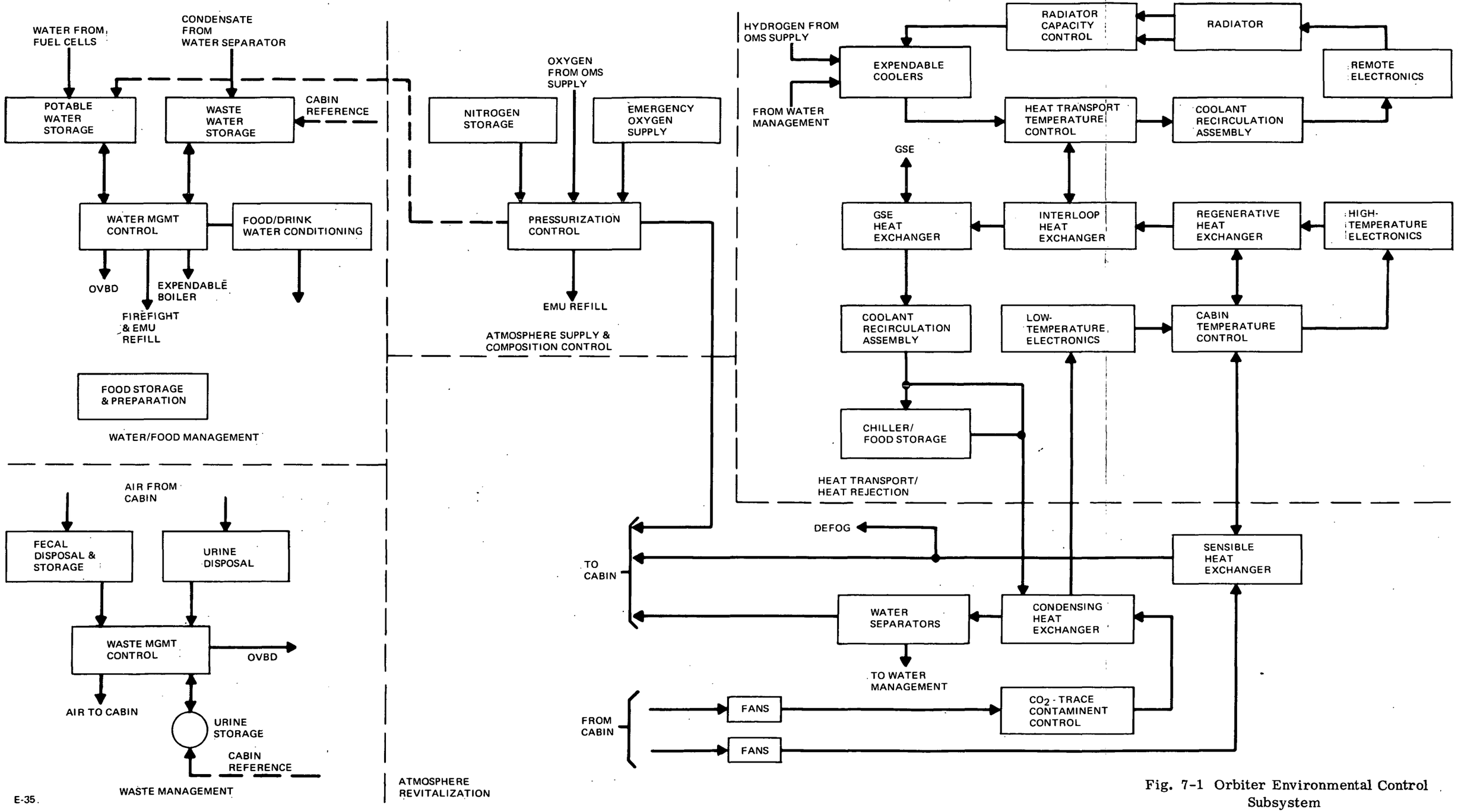


Fig. 7-1 Orbiter Environmental Control Subsystem



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The heat rejection loop will present two areas where development is not as straightforward as the previous sections. These are in the development of the hydrogen heat exchanger and the radiator. The $H_2$ exchanger is a new item and, as such, will require more development effort to arrive at an optimum design. However, the technology envolved does not go beyond present heat exchanger and boiler design knowledge but does require optimization and control system integration.

Radiator development will center around design optimization of individual panels and controls. This will include selection of a panel geometry as well as a coating. DFT testing will be used to optimize the panel design and verify calculated performance. A full-size radiator and attached cargo bay door structure will be fabricated and qualification tested with its control system. Since the radiators receive their structural support from the cargo bay doors, structural qualification will be a part of the structural test article.

Flight verification of the heat rejection system will take place partly during horizontal flight on the first vehicle and partly on the second vehicle during FMOF. During horizontal flight, the expendable cooler will be the sole source of heat rejection and will be a well proven backup to the radiator before orbital flight verifies that portion of the system.

### 7.1.3 ATMOSPHERE SUPPLY AND COMPOSITION CONTROL SECTION

This section's development will center about tankage design and the composition control module.

The baseline system for the $O_2$ - $N_2$ control module is similar to that used on Skylab and should present no major problems. Development of low flow regulators and control systems was a major part of Apollo and LM hardware, and experience gained from these programs should eliminate excessive trial designs in DFT.

Storage for gaseous high pressure nitrogen and emergency oxygen is baselined as filament-wound composite tanks. Technology in this area, although not as "cook book" as monolythic tankage, is developed to the point where no major problem is anticipated in tank design or manufacture.

### 7.1.4 WATER MANAGEMENT SECTION

This section will not present hardware development problems, since the majority of components will be scaled versions of LM and Apollo-type hardware. The only areas of concern in this section will be maintaining sterility in the stored water and development of a hydrogen separator to remove any residual hydrogen from the water supplied from the fuel cells.

Sterility maintenance is simplified in this system since the fuel cell product water is sterile when produced and the problem reduces to one of maintaining that condition until use. The baseline system uses a silver-ion generator in the water feed line to accomplish this. Although this item is developed, effort will be required to assure compatability with the shuttle system materials and use rates.

The hydrogen separator is presently baselined since experience on Apollo indicates a need to remove entrained $H_2$ from the potable water. This item will require development effort, and our experience gained on LM in separator design will be of considerable value.

## 7.2 ECS TEST PROGRAMS

### 7.2.1 EC/LS DEVELOPMENT TEST PROGRAM

All purchased components will undergo seller development and verification/qualification to develop and prove their design in accordance with the requirements established by the certification program for orbiter components. Sellers will also conduct tests at the assembly and/or section level to demonstrate that hardware functions properly when integrated.

A full-scale Grumman test rig will be provided to optimize interconnecting plumbing design and insure comfortable and effective heating, cooling, and airflow patterns within the occupied spaces and to verify the operation of the overall integrated EC/LS when installed and operated in the vehicle configuration. The rig will consist of sealed and insulated non-flight weight cabin and cargo compartments within the same framework and operating at sea-level conditions. Generally, the program will use an unmanned test approach with all equipment and metabolic heat loads simulated. The radiator panels will also be simulated by providing heat rejection with support equipment. By using the unmanned test approach, an accurate and timely evaluation of the subsystem will result without the

complexities introduced by the use of human test subjects. However, if the need arises for manned tests, the complexities involved would not be as significant as that experienced on some of the previous manned spaceflight programs because the internal atmosphere of the test rig will be under normal sea-level conditions.

### 7.2.2 RADIATOR TEST PROGRAM

The radiator test program consists of two phases: verification of analytical techniques used in the design of the panels; and certification of the thermal, structural, and mechanical performance of the radiator system. During each phase, simulation will include duplicating anticipated coolant flow rates, temperatures, and heat loads from supporting structure and radiative heat fluxes incident upon the radiator from the orbiter, Earth, Sun, and other orbital structures, where applicable. Additionally, certification phase environmental testing will include shock, vibration, and thermal cycling.

Existing thermal-vacuum facilities, flow control equipment, and instrumentation, which have the flexibility to permit testing of small representative panels or complete radiator assemblies are available in-house. Fixtures and procedures used in the development tests will be used for the certification program.

DEVELOPMENT

QUAL TEST

PRODUCTION HARDWARE

ACCEPT. TEST

SYSTEMS INTEGRATION

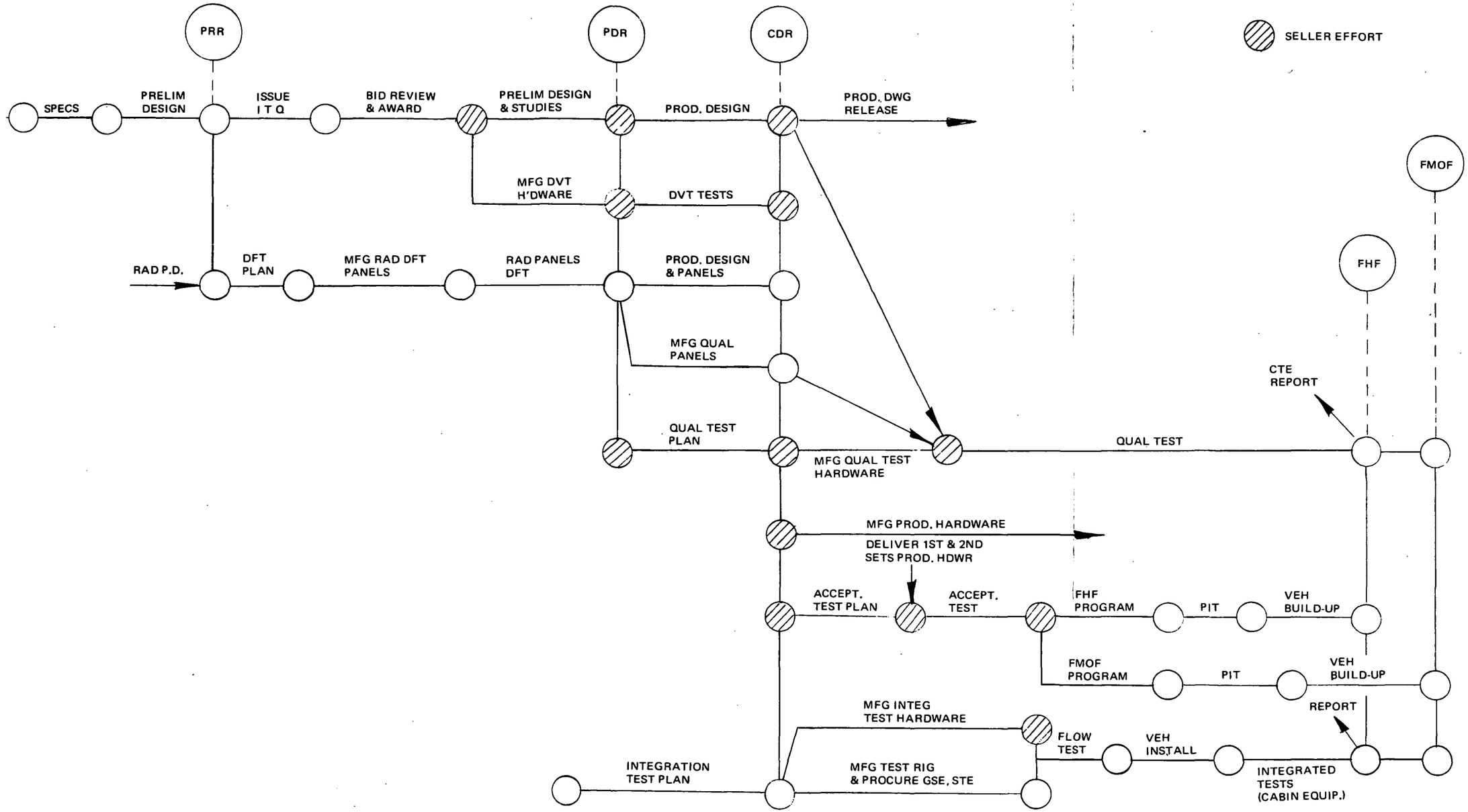


Fig 7-2 Environmental Control/Life Support Logic Network



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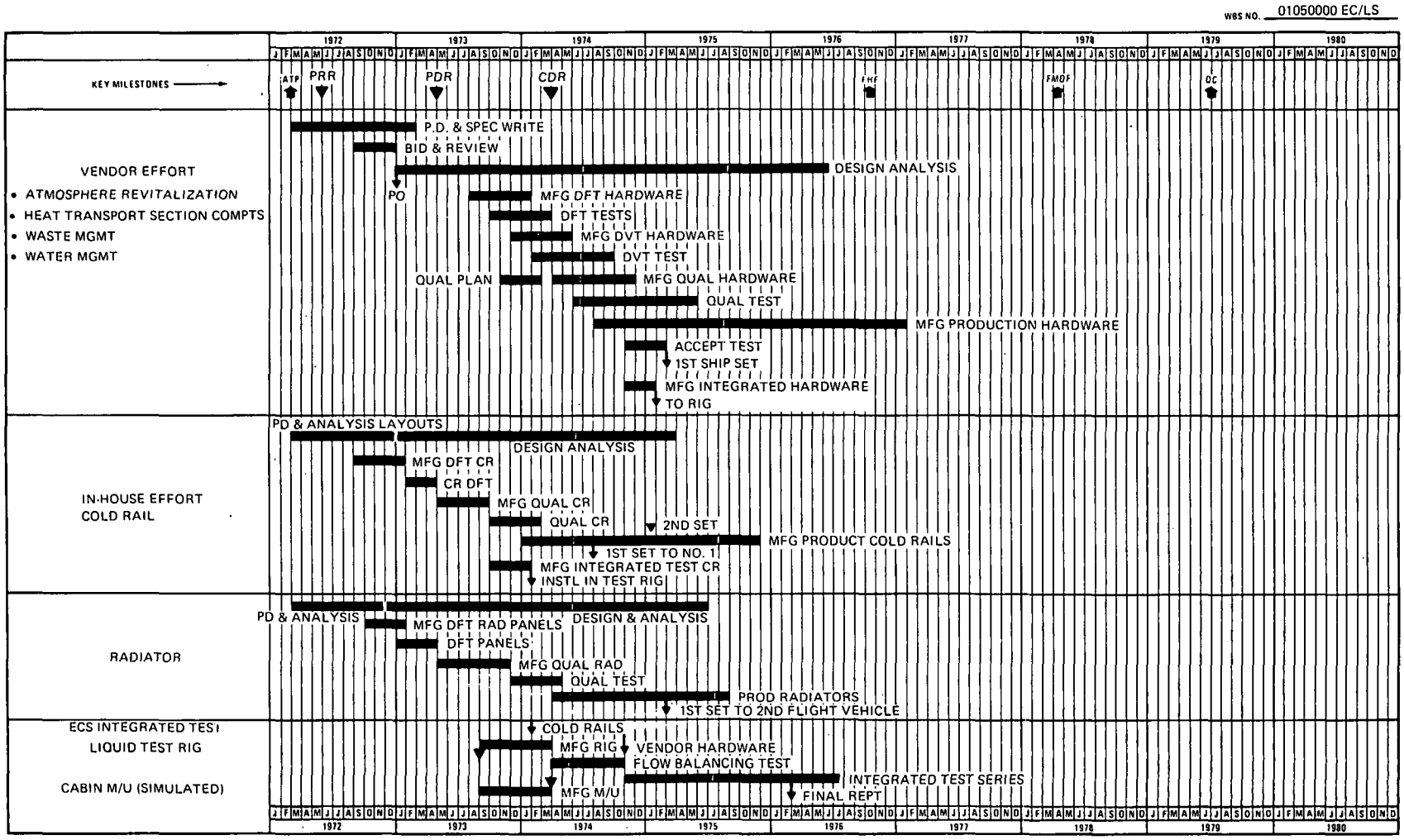



Fig. 7-3 Environmental Control/Life Support Schedule

TABLE 7-1. CERTIFICATION REQUIREMENTS FOR FIRST HORIZONTAL FLIGHT VEHICLE (Sheet 1 of 4)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| General | | | | | | | | | | | |
| • Equipment performs as specified while and after being subjected to environmental extremes of pressure, temperature, shock and vibration | | | | | | X | X | X | | | |
| • Assemblies and components are compatible with each other and with the vehicle & vehicle subsystems | | | | | X | | | | | X | X |
| • Equipment performs within tolerance limits specified for noise generation, EMI & electrical insulation & isolation | | | | | X | | X | X | | | |
| • Redundant components respond automatically & manually as specified | | | | | X | | | | X | X | |
| Atmosphere Revitalization Section | | | | | | | | | | | |
| • Certify that the ARS performs its specified functions. These are: | | | | | | | | | | | |
| - Adequate air is distributed for $CO_2$ & humidity control | | | | | X | | | | X | | X |
| - Specified limits on $CO_2$ & trace contaminant levels are maintained | | | | | X | | X | X | | | |
| - $CO_2$ onboard monitoring system performs as specified | | | | | X | | X | | | | X |
| - Air is cooled sufficiently in condensing heat exchanger for humidity control | | | | | X | | | X | X | | |

TABLE 7-1. CERTIFICATION REQUIREMENTS FOR FIRST HORIZONTAL FLIGHT VEHICLE (Sheet 2 of 4)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Atmosphere Revitalization Section (cont) | | | | | | | | | | | |
| - Water separators operate as specified to remove condensed moisture from the air stream | | | | | X | | | X | | | X |
| - Adequate cooling and heating is provided to the cabin atmosphere to ensure comfort to the crew | | | | | X | | | | X | | X |
| - Conditioned air is adequately distributed for window defogging | | | | | X | | X | | | | X |
| Heat Transport/Heat Rejection Section | | | | | | | | | | | |
| • Certify that the HTS performs its functions as specified. These are: | | | | | | | | | | | |
| - Adequately maintain electronic equipment within its specified limits | | | | | X | | | | | X | X |
| - Adequate flow and temperature are provided to the ARS to enable it to perform its specified functions | | | | | X | | | | X | | X |
| - Heat rejection to the GSE heat exchanger is as specified | | | | | X | | | | X | | |
| - Expendable cooler rejects heat as specified while operating independently of the radiator | | | | | X | | X | | | | X |
| - Adequate cooling of the fuel cell cooling loop is provided | | | | | X | | X | | | | X |

TABLE 7-1. CERTIFICATION REQUIREMENTS FOR FIRST HORIZONTAL FLIGHT VEHICLE (Sheet 3 of 4)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Atmosphere Supply and Composition Control Section | | | | | | | | | | | |
| • Oxygen is supplied from the OMS to the dual gas control module within specified tolerance limits | | | | | X | | | | | X | X |
| • Nitrogen is supplied from gaseous storage tanks to the dual gas control module within specified tolerance limits | | | | | X | | X | X | | | |
| • Emergency oxygen is supplied to oxygen masks or the dual gas control module by either automatic or manual controls within specified limits | | | | | X | | X | X | | | |
| • Cabin pressurization components maintain the partial pressures of the cabin gas constituents within specified limits | | | | | X | | | | | X | X |
| • Relief valves and compartment equalization valves automatically maintain total cabin pressures below specified limits and are compatible with manual crew operation | | | | | X | | | | | X | X |
| Water and Food Management Section | | | | | | | | | | | |
| • Water delivered from the fuel cells is compatible with the potable water storage system | | | | | X | | | | | X | X |

TABLE 7-1. CERTIFICATION REQUIREMENTS FOR FIRST HORIZONTAL FLIGHT VEHICLE (Sheet 4 of 4)

| Certification Requirements | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Water and Food Management Section (cont) | | | | | | | | | | | |
| • Water is supplied from the potable water tanks within specified limits for crew consumption, firefighting, EMU servicing, and waste water tank filling | | | | | X | | X | X | | | |
| • The heat dump nozzle adequately dumps waste liquids overboard | | | | | X | | X | | | | X |
| Waste Management Section | | | | | | | | | | | |
| • The waste management assembly adequately collects and stores liquid and solid wastes | | | | | X | | X | X | | | |
| • Sufficient flow and filtering is provided to contain and control odors | | | | | X | | X | X | | | |
| • The urine germicide components adequately maintain the urine collection components and storage tank within specified bacterial tolerance limits | | | | | X | | X | X | | | |
| • The urine storage tank is adequately emptied to the heat dump nozzle in the water management section | | | | | X | | | X | | | X |
| • The waste management section is physiologically acceptable to the crew | | X | | | | | | | | | |

TABLE 7-2. MAJOR COMPONENT LIST
(Sheet 1 of 4)

| Comp No. | Component Description | Qty/Vehicle |
|---|---|---|
| 101 | Humidity and $CO_2$ control fan | 3 |
| 102 | Fan check valve | 3 |
| 103 | LiOH cartridge | 9 |
| 104 | Condensing heat exchanger | 1 |
| 105 | Water collection duct | 1 |
| 106 | Cabin fan | 2 |
| 107 | Sensible heat exchanger | 1 |
| 108 | LiOH selector valve | 2 |
| 109 | Fan check valve | 2 |
| 110 | LiOH disconnects | 2 |
| 111 | Debris filter and silencer | 2 |
| 112 | Defog selector valve | 1 |
| 113 | Bypass valve | 1 |
| 201 | Accumulator, water | 2 |
| 202 | Pump assembly, water | 3 |
| 203 | Coldplates | 24 |
| 204 | Temp control valve, HTS | 2 |
| 205 | Interloop heat exchanger | 2 |
| 206 | GSE heat exchanger | 1 |
| 207 | Fill disconnects | 8 |
| 208 | Cold rails | 10 |
| 209 | Accumulator, freon | 2 |
| 210 | Pump assembly, freon | 3 |
| 211 | Hydrogen heat exchanger | 2 |
| 212 | Temp control valve, HTS | 2 |
| 213 | Temp controller, HTS | 1 |
| 214 | Sublimator | 1 |

TABLE 7-2. MAJOR COMPONENT LIST
(Sheet 2 of 4)

| Comp No. | Component Description | Qty/Vehicle |
|---|---|---|
| 215 | Space radiator | 1 |
| 216 | Regenerative heat exchanger | 2 |
| 217 | Temp controller, HTS | 1 |
| 218 | Hydrogen valve | 7 |
| 219 | Hydrogen regulator | 3 |
| 301 | High pressure nitrogen tank | 2 |
| 302 | Emergency oxygen tank | 1 |
| 303 | OMS $O_2$ regulator | 2 |
| 304 | $N_2$ pressure regulator | 4 |
| 305 | $O_2$ pressure regulator | 1 |
| 306 | Shutoff valve | 11 |
| 307 | $O_2$ check valve | 8 |
| 308 | $O_2$ overboard relief valve | 1 |
| 309 | $O_2$ burst disc | 1 |
| 310 | $O_2$ low pressure regulator | 2 |
| 311 | $O_2$ relief valve | 2 |
| 312 | $N_2$ bypass relief valve | 4 |
| 313 | $N_2$ overboard relief valve | 2 |
| 314 | $N_2$ burst disc | 2 |
| 315 | Purge valve | 1 |
| 316 | Control valve | 6 |
| 317 | Cabin regulator | 2 |
| 318 | Control | 1 |
| 319 | $O_2$ partial pressure sensor | 2 |
| 320 | Equalization valve | 4 |

TABLE 7-2. MAJOR COMPONENT LIST
(Sheet 3 of 4)

| Comp No. | Component Description | Qty/Vehicle |
|---|---|---|
| 321 | Cabin pressure relief valve | 3 |
| 322 | Pressure gage | 13 |
| 323 | $N_2$ service disconnect | 2 |
| 324 | $O_2$ service disconnect | 1 |
| 325 | $O_2$ backpack fill disconnect | 1 |
| 401 | Water storage tank | 2 |
| 402 | Hydrogen separator | 2 |
| 403 | Separator select valve | 1 |
| 404 | Check valve, water | 4 |
| 405 | Back pressure regulator | 2 |
| 406 | Silver-ion generator | 2 |
| 407 | Isolation valve | 6 |
| 408 | Service disconnect | 2 |
| 409 | Separator relief valve | 2 |
| 410 | Water heater | 1 |
| 411 | Water chiller | 1 |
| 412 | Water dispenser | 1 |
| 413 | Backpack fill hose | 1 |
| 414 | Shutoff valve | 5 |
| 415 | Dump valve | 1 |
| 501 | Waste collector | 1 |
| 502 | Control valve, M/O, N.O. | 2 |
| 503 | Control valve, M/O, N.C. | 2 |
| 504 | Urinal | 2 |
| 505 | Biocide tank | 1 |
| 506 | Biocide injector | 2 |

TABLE 7-2. MAJOR COMPONENT LIST
(Sheet 4 of 4)

| Comp No. | Component Description | Qty/Vehicle |
|---|---|---|
| 507 | Filter, particulate | 1 |
| 508 | Check valve, gas | 8 |
| 509 | Check valve, liquid | 7 |
| 510 | Waste liquid tank | 1 |
| 511 | Liquid/gas separator/fan/pump | 3 |
| 512 | Odor filter | 1 |
| 513 | Bacteria filter | 1 |
| 514 | Overboard dump nozzle/control | 1 |
| 515 | Dump control valve | 2 |
| 516 | Biocide disconnect | 1 |
| 517 | Isolation valve | 1 |
| 518 | Equalization valve, M/O | 1 |
| 519 | Urinal valve, M/O | 2 |

TABLE 7-3. REQUIRED EQUIVALENT UNITS

| Hardware Description | Required Equiv Units |
|---|---|
| Flight hardware per vehicle | 1 |
| Component Dev and Qual test | 4 |
| Integration tests | 1.5 |
| • Full mission simulation lab | |
| • Integrated avionics test lab | |
| • Flight controls hydraulic test lab | |
| • Mechanical sys test rigs | |
| • Prop. fluid breadboards | |
| • Escape sys test rig | |
| Test articles | |
| • Propulsion test article | 0.25 |
| • Structural test article | 0.5 |
| Spares for 445 flights | 5 |
| Spares for flight test program | 2 |

TABLE 7-4. BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Not Common | Remarks |
|---|---|---|---|---|
| Oxygen masks | | X | | |
| Cabin pressure relief valve | | X | | If booster follows standard aircraft cycle, i.e., maximum differential of 8 psid, commonality may be prevented |
| High pressure tankage | | X | | Booster air tank, orbiter emergency oxygen tank |
| Cabin fans | | X | | |
| Backup waste collection bags | X | | | Supplied by shuttle system integrator |
| Cryogenic heat exchanger | | X | | Different sizes may be required, same development technology |
| Portable fire extinguisher | | X | | |
| Coolant pumps | | X | | |
| Misc valves, regulators, and disconnects | | X | | Commonality candidates will be defined during detail design |

TABLE 7-5. SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Integrated rig<br>- Data acquisition system - 300 channel<br>- Control and monitoring console<br>- Gas analyzer<br>- Freon servicing rig<br>- Water servicing rig<br>- Oxygen supply and transfer<br>- Nitrogen supply and transfer<br>- $CO_2$ supply<br>- Water supply (demineralized, potable)<br>- Freon supply<br>- Metabolic simulator<br>- Air and liquid flow measurement, noise meter, air velocity meter, humidity indicator<br>- Radiator simulator and fluid conditioning control<br>- Leak detector (existing)<br>• Radiator thermal vacuum tests<br>- Data acquisition system (existing)<br>- Fluid conditioning and control (existing)<br>- Vibration equipment (existing)<br>- Liquid nitrogen supply and transfer (existing) |
| Software | • Atmosphere revitalization section simulation<br>• Heat transport section simulation - steady state, transient<br>• Radiator loop simulation - steady state, transient<br>• Integrated loop simulation - transient<br>• Component performance |

TABLE 7-6. FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. |
|---|---|---|
| • Integrated Test Rig | | |
| - Test area: 4000 sq ft high bay | | X |
| - Engineering office, shop area, microbiology, and chemistry labs | | X |
| - Vacuum pump and enclosure (for vacuum fill of Freon system, desiccant drying, cabin purge) | X | |
| - Nitrogen, oxygen, $CO_2$ storage pads | X | |
| - Electrical power: 60 Hz, 3 Phase, 120V; 400 Hz, 3 Phase, 120V; 28 vdc | | X |
| • Thermal Vacuum Test Radiator | | X |
| - Thermal vacuum chamber with mounting gimbal, cold walls, quartz array | | X |
| - Test area, engineering, and shop areas | | X |

TABLE 7-7. EC/LS SUBSYSTEM COMPUTING REQUIREMENTS

| | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Keypunch* (Total Hours per Year) | 150 | 200 | 180 | 140 | 120 | 100 | 60 | 50 | 50 | 50 | 50 | | | | | | 1150 |
| Machine Time Estimate | | | | | | | | | | | | | | | | | |
| 360-75 | 60 | 100 | 80 | 60 | 30 | 20 | 10 | 5 | 5 | 9 | 5 | | | | | | 384 |
| 360-67 | 30 | 50 | 40 | 30 | 15 | 10 | 5 | 2 | 2 | 2 | 2 | | | | | | 188 |
| 360-30 | 30 | 50 | 40 | 30 | 15 | 10 | 5 | 2 | 2 | 2 | 2 | | | | | | 188 |

RATIONALE (explain briefly the basis for your estimate, for example, the number of revised programs or new programs anticipated)

- 3 revised major programs
- 3 new major programs
- 20-30 new minor programs

* assume 50 cards per hour

PAYLOAD INTEGRATION

Section 8

# PAYLOAD INTEGRATION

This activity includes the engineering, quality control, manufacturing, test and facilities support required of the orbiter contractor to prepare for and perform the work of installing types or classes of payloads in the orbiter, and of physically accomplishing the structural, mechanical, thermal, electrical, fluid and alignment interfacing between the payload and the orbiter. Similar support, leading to the incorporation, checkout and use of payload ground equipment within the orbiter ground equipment complex, is also included in this task. General payload coordination and liaison activities are performed to insure basic compatibility between payloads and the orbiter.

## 8.1 ENGINEERING SUPPORT FOR PAYLOAD INTEGRATION

This task includes the design, analysis, planning and interface control for prototype payloads and payload ground equipment integration, as well as the physical installation of payload ground equipment in the orbiter ground equipment complex.

### 8.1.1 THERMAL CONTROL ANALYSIS

Thermal analyses are performed to determine the degree of thermal compatibility existing among payloads, and the orbiter and its associated subsystem. These analyses are used to determine the degree and nature of thermal tailoring provisions required of the payload and the orbiter to meet prototype payload performance; such provisions include:

- Modification to tie down fittings
- Changes in mounting thermal characteristics
- Locating suitably designed thermally conductive straps
- Thermal payload bay $\alpha/\epsilon$ modification and trim-up

For planning purposes, it is assumed that the prototype payload defines a class of experiment payloads requiring the above analysis to be accomplished only once.

### 8.1.2 STRUCTURAL ANALYSIS

Structural analyses are performed to ensure that the static and dynamic interactions between the payload and the orbiter does not exceed the specified limits. Based upon these analyses, the degree and nature of structural modifications (if any) required of the payload to meet performance specifications are determined. Such modifications in general are minor in nature, involving support relocation, change in number of and locations of attachment points to ease local stress conditions, and potential modifications to attachment fitting design.

This task supplements the stress analysis activity performed on the basic payload and on the orbiter itself since it is aimed at disclosing those design modifications required to meet the performance requirements of the payload when it is installed in the orbiter.

### 8.1.3 DYNAMIC ANALYSIS

Transient and steady state dynamic analyses are performed to insure that the payload, when mounted in the orbiter, meets the dynamic load levels of the performance specification. Based on this analysis, the degree and nature of minor structural modifications (if any) required of the payload to meet system performance specifications is determined. This task provides the analytical basis to resolve minor design modifications which may be required of the prototype payload due to its unique characteristics.

### 8.1.4 DESIGN

The orbiter design undergoes minor modifications required to accommodate the prototype payload. These modifications are based on the results of the thermal analysis, structural analysis, dynamic analysis and final prototype payload information. Candidates for such design changes include modification to support (tie down) fittings, minor relocation of baffles, provision for access doors, attachment of suitably designed thermal straps within the payload bay, and thermal $\alpha/\epsilon$ modification and trim up for the payload bay. This activity is pursued in sufficient depth to permit fabrication of parts to accomplish the prototype payload integration task.

### 8.1.5 INTERFACE CONTROL

Control over payload integration requirements is exercised by submitting changes, as appropriate to the interface control documents (ICD's) to ensure that payload integration efforts are documented for the cognizance and use of the program.

## 8.2 PAYLOAD INSTALLATION

Requirements for facilities and services to support the tasks associated with prototype payload installation are identified; these tasks include the following:

- Inspection of incoming payload
- Installation in the orbiter
- Determination of mass properties and balance requirements
- Installation of ballast
- Testing of EMI characteristics
- Final inspection of the overall installation

## 8.3 MOCKUP AND SIMULATION

Mockup and simulation activities associated with payload integration are described in Section 10.

## 8.4 CERTIFICATION REQUIREMENTS

Certification requirements are listed in Table 8-1.

E/8.1

TABLE 8-1 CERTIFICATION REQUIREMENTS (Sheet 1 of 4)

| Requirements | Certification Method | | | | | | Level of Assembly | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle | Integ Test Art. |
| • Design Requirements | | | | | | | | | | | | |
| 1. Direct delivery of payload to a specified orbit or recovery of a payload from a specified orbit. | X | | | | | | | | | | | |
| 2. Indirect delivery of the payload by placement of a payload and propulsion stage in a parking orbit for subsequent transfer to a specified operational orbit with possible station keeping for retrieval of the propulsion stage. | X | | | | | | | | | | | |
| 3. Serve as a base for short duration orbital missions (up to 30 days). | X | | | | | | | | | | | |
| 4. Provide for routine and/or special support to space activities such as rescue, repair, maintenance, servicing, etc. | X | | | | | | | | | | | |
| • Operational Requirements | | | | | | | | | | | | |
| 1. Capability of hold down locks to hold cargo/container secure under all loading conditions. | X | | | | | X | | | X | | | X |
| 2. Capability of hold down locks to lock and unlock under loads/environment. | X | | | | | X | | | X | | | |
| 3. Capability of deployment mechanism to deploy and retrieve payloads. | X | X | | | | X | | X | | | X | |

TABLE 8-1 CERTIFICATION REQUIREMENTS (Sheet 2 of 4)

| Requirements | Certification Method | | | | | | Level of Assembly | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle | Integ Test Art. |
| Operational Requirements (Cont) | | | | | | | | | | | | |
| 4. Capability of docking mechanism between cabin and payload to lock and unlock automatically. | X | | | | | X | | | X | | | |
| 5. Capability of shuttle support functions to engage/disengage with payload/s. | X | | | | | X | X | | | | | |
| • Interface Requirements | | | | | | | | | | | | |
| 1. Payload/payload container to deployment mechanism. | X | X | | | | X | | X | | | | |
| 2. Payload - Hold down locks | X | X | | | | X | | X | | | | |
| 3. Payload - Cabin bulkhead universal docking mechanism. | X | X | | | | X | | X | | | | |
| 4. Payload envelopes for less than or equal to 15 ft diameter and 60 ft length. No constraint on minimum module diameter or length. | X | X | | | X | | | | | | X | |
| 5. Capability to deploy payload on orbit, including docking payloads to stabilized third body. | X | X | | | | X | | X | | | X | |
| 6. Capability of docking to stabilized modules with subsequent retrieval, handling and stowage for orbit transfer or return to earth. | X | X | | | | X | | X | | | X | |

TABLE 8-1 CERTIFICATION REQUIREMENTS (Sheet 3 of 4)

| Requirements | Certification Method | | | | | | Level of Assembly | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle | Integ Test Art. |
| Interface Requirements (Cont) | | | | | | | | | | | | |
| 7. The cargo bay includes provisions for a vent system for payload with minimum attitude and velocity disturbance to orbiter. | X | X | | | | X | | | | | X | X |
| 8. The payload C. G. envelope is within orbiter capabilities. | X | | | | | | | | | | X | |
| 9. Monitoring status of deployment mechanism, payload and payload systems during all phases of operation shall be included. | X | | | | | | | | | X | X | X |
| 10. Orbiter payload bay doors have capability of exposing entire length and width of max. size payload. | X | | | | | | | X | | | | X |
| 11. Cargo bay doors open to allow 180° lateral field of view for payloads mounted at hinge plane. | X | | | | X | | | X | | | | |
| 12. Standard deployment mechanism deploys payload to clear orbiter mold line. | X | | | | | | | X | | | | X |
| 13. Release of payload from deployment mechanism leaves payload and orbiter in stable mode min-disturbing torque. | X | | | | | | | | | | X | |

TABLE 8-1 CERTIFICATION REQUIREMENTS (Sheet 4 of 4)

| Requirements | Certification Method | | | | | | Level of Assembly | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analysis | Simulation | Similarity | Common Usage | Test | | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle | Integ Test Art. |
| | | | | | DVT | Qual | | | | | | |
| Interface Requirements (Cont) | | | | | | | | | | | | |
| 14. Retrieval mechanism capable of retrieval and stowage of reusable payload modules in reverse order of deployment. | X | | | | | X | | X | | | X | |
| 15. Capability is provided for determining mechanical alignment of fixed payloads to reference axis system of orbiter. | X | | | | | | | | X | | X | X |
| 16. Removal of docking hardware in whole or part thru docking port. | X | | | | X | | | X | | | | |
| 17. Supply up to 20 KWH of electrical energy to payload bay in regulated DC&/or AC-power (limited to 500 watt average with 800 watt peaks) | X | | | | | X | | | X | | | X |
| 18. Standardized connectors and junction boxes in cargo bay to interface with orbiter electrical system. | X | | | | X | | | | X | | | |
| 19. Verify Acoustical/Dynamic/Stock Vibration Compatibility | X | | | | X | | X | | X | X | | X |
| 20. Verify thermal vacuum compatibility. | X | | | | X | | X | | X | X | | X |

TEST VEHICLE CONVERSION

Section 9

# TEST VEHICLE CONVERSION

Following the completion of their respective test programs, the three major test vehicles are recycled and refurbished into deliverable operational orbiters. The vehicles to be converted are the horizontal flight test article, the orbital flight test article, and the propulsion test article. Each vehicle serves a different purpose in the development program and has a configuration unique to its role. Therefore, the degree of conversion differs widely, as explained below.

## 9.1 HORIZONTAL FLIGHT TEST ARTICLE REFURBISHMENT

The test article used for the horizontal flight test program is a production vehicle built at the main shuttle assembly facility at Michoud, La. This is a complete flight-weight structure not including the final TPS design.

Prior to its use in the horizontal flight test program, this orbiter was outfitted with special equipment and instrumentation necessary to ensure the safety of the crew and the achievement of the flight test objectives. In addition, during its initial assembly, several subsystems and many items of equipment were not installed because they were not needed to meet test objectives, or were not available, or were omitted to minimize risk.

The horizontal flight testing is conducted at KSC, and extends over a period of a year. During this time, numerous flights are conducted with the heavily instrumented vehicle to evaluate the aerodynamic properties and the ABES propulsion system of the orbiter. A flow diagram (Fig. 9-1) depicts the sequence in the conversion of the horizontal flight test switch to a deliverable orbiter.

### 9.1.1 TEST ARTICLE INSPECTION

Upon completion of its last horizontal flight test, the orbiter is thoroughly inspected for failed, damaged, or used parts and/or equipment. The inspection concentrates on basic structural elements to assure that there are no parts which exhibit signs of creep, fatigue, or stress corrosion. If any failed, damaged, or used parts are detected these are replaced

and, if it is appropriate (i.e., if it is judged to be caused by a design deficiency), the part(s) are redesigned and tested for retrofitting into all flight vehicles.

The inspection of the primary structure is performed at Michoud using visual and NDE techniques such as dye penetrant, ultrasonics, and radiography.

9.1.2 REMOVAL OF SPECIAL EQUIPMENT

The following special equipment and instrumentation is removed from the orbiter:

- The ferry air breathing engine system (ABES) "package" including the extra engine, extra fuel tank installed in the cargo bay, air data system, anti-icing system, etc.
- The development flight instrumentation (DFI) "package" including sensors, conditioning equipment, computer, recorders, and associated displays, controls, and wiring.
- Ejection seats and controls
- Special flight control system (FCS) power "package" (hydraulic and electrical power supply) with special provisions for a subsequent phase-in replacement by APU's.
- Bare metal skins (in all areas where E.I., Haynes, Columbium, and Carbon-Carbon TPS is normally installed) with special "cut-out" provisions to install candidate TPS panels in locations on fuselage, wings, tail rudder, leading edges, and chines
- Ballast for missing equipment/payload and covers/seals over uninstalled equipment locations
- Special displays, controls, wiring and bracketry for all special equipment

9.1.3 INSTALLATION OF EQUIPMENT OMITTED DURING THE FLIGHT TEST PROGRAM

The following equipment is installed into the orbiter:

- Main propulsion system (MPS) engines, tanks, lines, and valves
- Orbit maneuvering systems (OMS) engines, tanks, lines, and valves
- Reaction control system (RCS) engines, tanks, lines, valves, and TPS doors

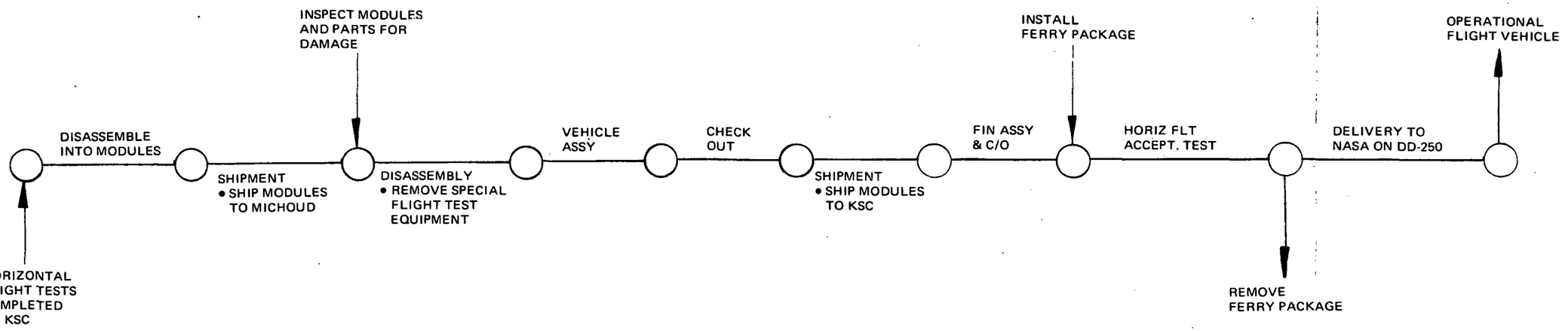





Fig. 9.1 Horizontal Flight Test Article Conversion Logic

- Auxiliary power units (APU's) and fuel cells, with their lines and valves
- Rendezvous and docking equipment, and airlock
- Cargo bay deployment and retrieval system, and payload handlers' crew station equipment including panels, displays, and controls
- TPS (qualified)
- EC/LSS (qualified)
- Operational instrumentation for the above equipment
- Avionics and displays, controls, wiring, and bracketry for above equipment

## 9.2 ORBITAL FLIGHT TEST ARTICLE REFURBISHMENT

### 9.2.1 TEST CONFIGURATION

The second orbiter vehicle in the production line is used for orbital flight testing from KSC for a period of approximately 14 months. This vehicle is of a final flight configuration except for special provisions for the test program. The vehicle is horizontally flight-tested after delivery to KSC, and then used for the development of pre-launch checkout and servicing procedures. Vertical flights are launched using the shuttle booster, and all flights are manned. All flights are orbital, lasting up to seven days (or longer) and returning to the main shuttle operational area at KSC. The vehicle has propulsive capability for orbital insertion, orbital maneuvering and attitude control, de-orbit impulse and for maneuvering for landing in the atmosphere. All subsystems for life support, navigation, communication, etc., are installed. Special provisions required for the initial flight include:

- Added thermal shielding, besides the TPS
- DFI instrumentation system with RF link
- Ejection seats for crew
- Ballast for missing payload weight
- Provision for installation of an additional fuel tank in the cargo bay for ABES

### 9.2.2 POST-FLIGHT INSPECTION

Each orbital flight is followed by a complete inspection and/or refurbishment of the vehicle. After landing at KSC, the vehicle tanks are drained and purged, and all pressurized containers vented. The orbiter is then towed into the MCMB for a comprehensive status check. The details of the inspection are covered in the operations plan, but include verification of structural integrity, check and repair of the TPS, and a search for damage, fatigue, and stress corrosion. All seals are leak-checked and replaced if necessary. The activities between flights are aimed at developing recycling procedures for operational flights, as well as providing a reliable vehicle for the next flight test.

### 9.2.3 REFURBISHMENT INTO OPERATIONAL VEHICLE

After the completion of the flight test program, a major teardown and inspection is performed on this vehicle at the MCMB. Since the vehicle is essentially complete, structurally and functionally, it is not shipped back to the main assembly plant at Michoud. As part of the inspection, the entire TPS is removed, the MPS and OMS engines removed, the DFI system uncoupled from the vehicle, and all access doors removed for better visibility of the primary structure (internally as well as externally). The inspection concentrates on evidence of structural creep, fatigue, and stress corrosion, as well as the integrity of all seals, mechanical joints, and electrical connections. During this time, all special flight test equipment is removed. The rocket engines are inspected and refurbished separately by their respective contractors.

The buildup of the vehicle to convert it to operational status consists of re-installation of all equipment removed for the inspection, as well as the mission equipment not used for the flight tests. New hardware, not used previously, consists of the following:

- Qualified/operational TPS
- Rendezvous and docking equipment
- Operational instrumentation

## 9.3 MAIN PROPULSION TEST ARTICLE (PTA) REFURBISHMENT

### 9.3.1 TEST CONFIGURATION

The test article used for the cold-flow and cluster firing of the main propulsion subsystem consists of the flight weight orbiter midbody structure incorporating the integral $LO_2$ tanks, the propellant feed ducts, the engine thrust mounts, and portions of the bare metal skins.

The crew compartment, wings, and other aerodynamic surfaces are not required. Since it is planned to use semi-heavyweight $LH_2$ tanks, the external tank attachment points and supporting structure are of special reinforced design. It is also necessary to use special base heat shields and acoustic noise suppressors in the main engine compartment area. Besides the DFI system, additional transducers are installed throughout the vehicle to measure temperatures, pressures, strain, vibration, and acoustic noise. This PTA vehicle is tested in an ambient (sea level) pressure environment for a period of approximately 14 months.

### 9.3.2 POST-TEST INSPECTION AND DISASSEMBLY AT KSC (OR MTF)

Upon completion of the static firing tests, the test article is removed from the test stand and then taken to the shuttle assembly building for inspection. Portions of the PTA are disassembled, as discussed later, and the vehicle inspected for obvious signs of damage or corrosion. The PTA structure, is then shipped to the main shuttle manufacturing area (Michoud, La.) for refurbishment into operation flight vehicle no. 4. A flow diagram (Fig. 9-2) depicts this sequence.

Before removing from the test stand, the vehicle tanks and feed system are vented and purged with inert gas. The engine nozzles are in a retracted position and the gimbal actuators nulled and locked. The pneumatic and hydraulic systems are depressurized. Prior to moving the PTA to the maintenance/checkout/mating building (MCMB), the heavyweight $LH_2$ tanks are detached and placed into storage. All special shielding used for the static firings, as well as transducers and test instrumentation cables, are removed. A gross leak check of the MPS, including engines, is performed. Cursory inspection of the structure, skins, fittings, and fluid lines is performed to detect corrosion or discoloration, and these are documented. The PTA vehicle is then barged to the shuttle assembly facility at Michoud.

### 9.3.3 TEST ARTICLE INSPECTION

At the main assembly facility the vehicle skins, main engines, and other special test hardware are removed to enable a detailed inspection of the primary structure. The equipment to be removed at Michoud consists of:

- All supplementary development instrumentation and associated wiring harnesses
- Reinforced structure and brackets used for the heavyweight $LH_2$ tanks and base heat shield
- APU and hydraulic components needed for thrust vectoring
- Special fittings and adapters at the booster separation points (used to mate PTA to static firing test stand)
- Portions of electrical system used for testing only
- All skins and thermal shielding

The engines are packaged and shipped to the engine contractor's facility for detailed teardown and inspection. The results of the post-firing inspection determine, in part, the engine refurbishment requirements after each operational flight. These main engines are then rebuilt and allocated as operational spares to the shuttle program.

The entire primary structure undergoes an inspection using both visual and NDE techniques. These include use of dye penetrant, ultrasonics, and radiography. The magnitude of structural refurbishment depends on the results of this inspection. The integrity of all cryogenic vacuum-jacketed lines which could not be removed is also verified.

### 9.3.4 REFURBISHMENT AND REASSEMBLY

The PTA primary mid-body structure is rebuilt and/or modified to bring the vehicle to a flight configuration. When this is complete, the other structures and equipment (not originally required for the test program) are installed. The exact sequence is shown in the manufacturing plan, and includes the following:

- Wings, tail rudder structure, elevons and nose
- Cabin and crew compartment, including control panels and displays

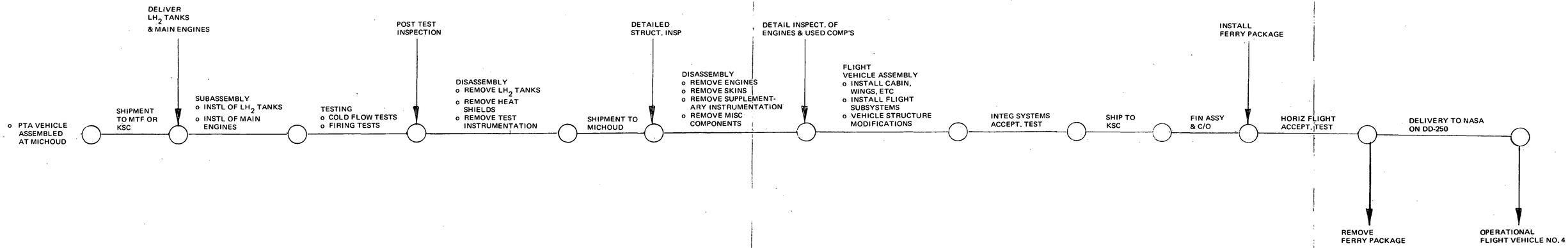



Fig. 9.2 Propulsion Test Article Conversion Logic



GRUMMAN BOEING

- Fore and aft landing gear
- Separation and docking mechanisms
- Flight control subsystem, actuators, and hydraulic system
- Auxiliary power units, including hydraulic pumps, generators, and fluid lines and valves
- Electric power subsystem, cabling, fuel cells, and batteries
- ACPS (engines, tanks, lines, and valves)
- MPS (engines, interface connections, and hydraulic actuators)
- OMS (engines, tanks, lines, and valves)
- Environment control and life support subsystems
- All avionics equipment including antennas
- ABES (engine, tanks, lines, valves, and deployment mechanisms)
- TPS and thermal insulation
- Onboard checkout/caution and warning system

SYSTEM TESTS

# Section 10

## SYSTEMS GROUND TESTS

The Systems Ground Test Program is required to support the design, development and manufacture of the orbiter and encompasses the following broad categories:

- Full-scale engineering mockups
- Full-scale systems test articles
- Flight vehicle modal vibration survey
- Integrated Systems Test and Simulation

Full-scale engineering mockups are described in Section 10.1 and include:

- Crew/passenger accommodations and neutral buoyancy mockups
- Payload integration mockup
- Structures, line runs, equipment integration mockups
  - Airbreathing engines deployment mockup
  - Landing gear/TPS doors deployment mockup
- Main propulsion/base heat shield/structural mockup

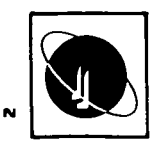
These mockups simulate orbiter structural, mechanical and subsystem elements and are essential as engineering tools early in the program. Mockup configurations will parallel design evolution and will verify new design concepts in a timely fashion.

Full scale systems test articles will include the following:

- Structural Test Article (Subsection 10.2)
- Propulsion Test Article (Subsection 10.3)
- Escape System Test Rig (Subsection 10.4)







These test articles will provide the means to establish a systems confidence level which allows acceptance of lowered design margins, thereby optimizing subsystem and system designs. When performance satisfies mission requirements, design adequacy is demonstrated; excess capability or performance will indicate areas for further optimization. These major test articles are in Subsection 10.2, 10.3 and 10.4.

The flight vehicle modal vibration survey, outlined in Subsection 10.5, is a major test program conducted to determine the significant structural vibration modes, and the structural damping characteristics of the orbiter. It will serve to verify analytic predictions and will provide the foundation for subsequent dynamic load and stability studies.

The integrated systems test and simulation program, outlined in Section 10.6, will utilize existing laboratories to support the design and verification of the orbiter systems and subsystems. These separate facilities, i.e., mission simulation, avionics integration, and flight controls are so organized that they can be combined when necessary into a Full Mission Integrated Test Facility for the comprehensive testing of combined systems.

# 10.1 MOCKUPS

## 10.1.1 CREW/PASSENGER ACCOMMODATIONS MOCKUPS AND ZERO GRAVITY TEST ARTICLES

A series of increasingly refined mockups will be provided as illustrated in Fig. 10.1-1.

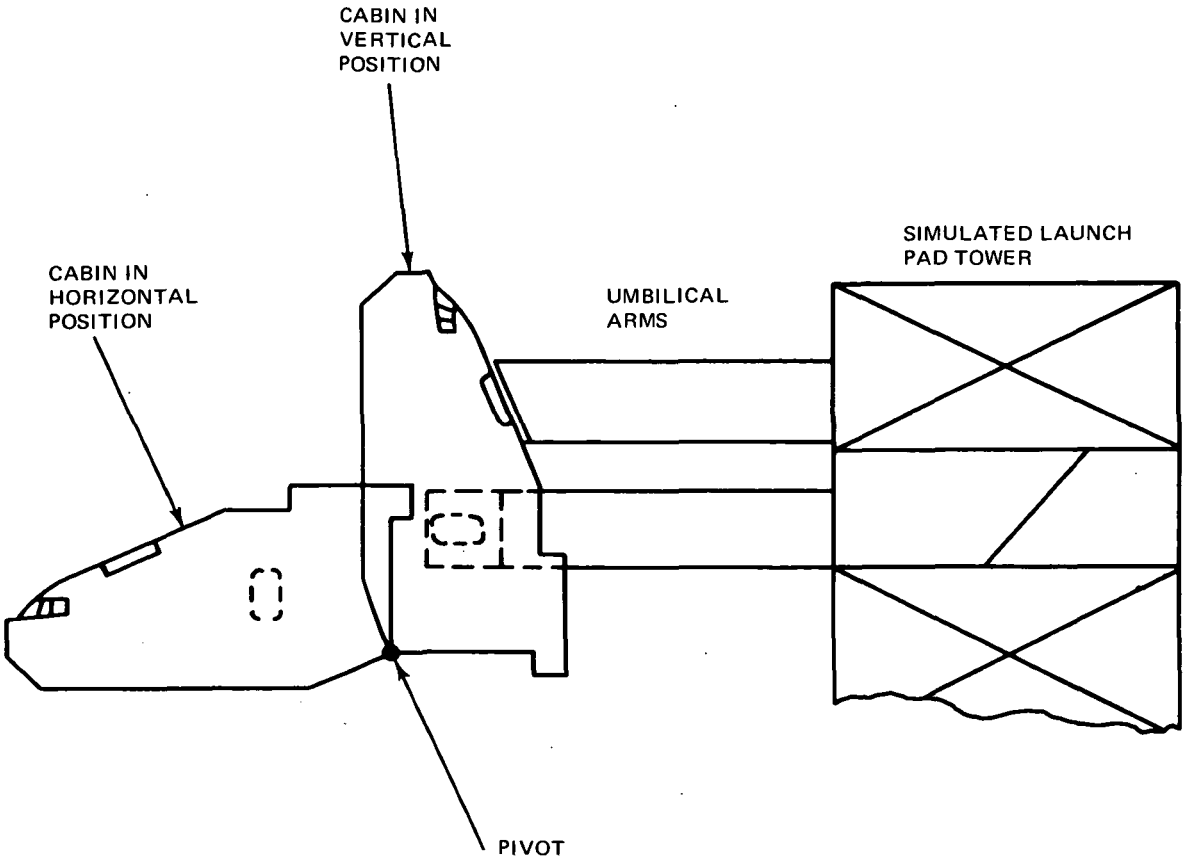
A pre-Phase C/D soft mockup will depict the flight station, passenger arrangements, displays and controls, and ingress/egress capability. It will be positionable in the horizontal, flight, launch, and reentry orientations.

The pre-Phase C/D soft mockup will be updated for the Program Requirements Review (PRR). A new Preliminary Design Review (PDR) mockup will be constructed of soft materials and used for timely GFE and CFE hardware arrangement and verification of crew interfaces responsive to the mission profile modes. Concurrently, with the PDR mockup construction, a hi-fidelity mockup of simulated working or actual hardware will be started. It will be constructed of flight materials representative of the actual size of controls, displays structural members system and subsystem plumbing and electrical runs necessary for the flight crews evaluation during the Crew Compartment, Stowage Review (CCSR).

Preliminary lighting concepts will be installed and evaluated by the contractor and customer in the PDR mockup. Decisions at the review will allow the contractor to proceed with flight hardware procurement. Updated lighting hardware will be reviewed in the CDR mockup. Prototypes of the final flight lighting hardware will be reviewed in the hi-fi mockup and form the basis for installation of lighting hardware into production vehicles

Hardware design interfacing with the crew and passengers must be validated in a zero gravity environment. As in Apollo this will be achieved in part task KC-135 flight test articles (Fig. 10.1-2) and full cabin test articles (Fig. 10.1-3) in NASA operated neutral buoyancy tanks. These test articles may also be used by the crew and passengers as training devices in preparing for each mission.

Crew mockup certification requirements, support requirements and facility requirements are shown in Tables 10.1-1, 10.1-2, and 10.1-3.




MOCK-UP DESIGNATIONS

| | |
|---|---|
| SEB | SOFT MOCK-UP COMPLETED PRIOR TO RFP, UPDATED FOR PRR |
| PDR | SOFT MOCK-UP COMPLETED IN TIME FOR PDR |
| CDR | SOFT/HARD MOCK-UP COMPLETED FOR CDR |
| HI-FI | HARD MOCK-UP COMPLETED IN SUPPORT OF FIRST FLIGHT ARTICLE |
| LIGHTING | LIGHTING EQUIPMENT INSTALLED IN HI-FI MOCK-UP (PRELIMINARY LIGHTING MOCK-UPS PERFORMED IN PDR/CDR MOCK-UPS) |

E-29

Fig. 10.1-1 Cabin Mock-Ups

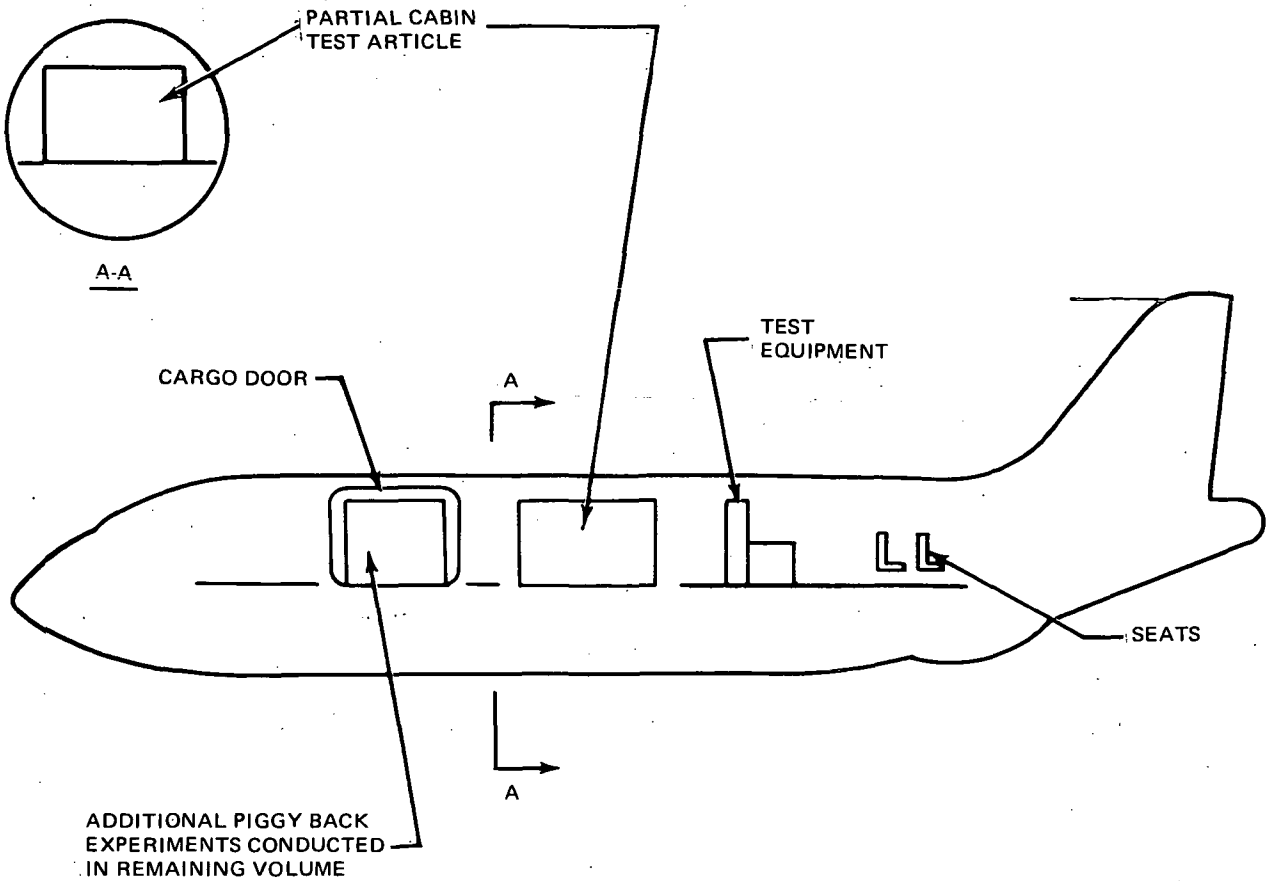
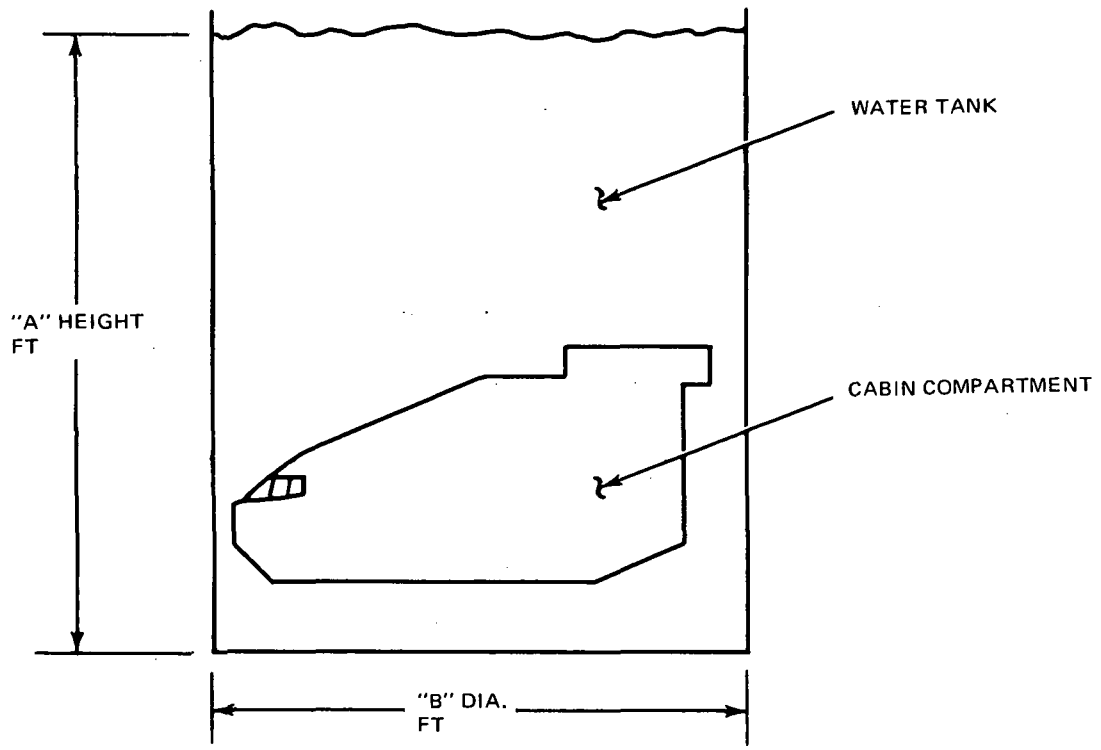





Fig. 10.1-2 "O" Gravity Test Article

TANK DIMENSION AT:

| | MSC | MSFC | LANGLEY |
|---|---|---|---|
| A | 16 | 40 | 20 |
| B | 28 | 75 | 40 |




E-30;

Fig. 10.1-3 Neutral Buoyancy Test

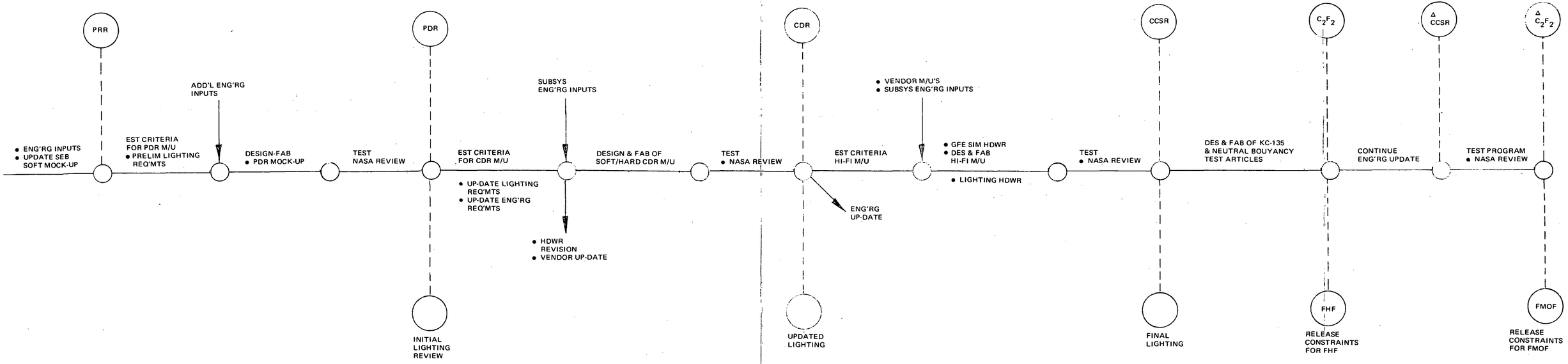





Fig. 10.1-4 Crew Station/Equipment & Passenger Accommodations Mockups Logic Network

TABLE 10.1-1 CREW MOCKUP CERTIFICATION REQUIREMENTS

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | QUAL | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Hi-Fi Mockup | | | | | | | | | | | |
| • Validate design of all hardware interfacing with the flight crew and passengers. The hi-fi mockup is to be used for this purpose at official NASA Crew Compartment Stowage Reviews (CCSR). The success of these tests will minimize the changes at the Crew Compartment Fit & Function ($C^2F^2$) Reviews on Flight Articles | | X | | | | | X | X | X | | |
| "O" Gravity & Neutral Buoyancy Test Articles | | | | | | | | | | | |
| • Validate functional design of hardware used by flight crew and passengers during a zero gravity environment | | X | | | | | X | X | X | | |

TABLE 10.1-2 CREW MOCKUP SUPPORT REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | • Pressure Suit Donning/Doffing Room.<br>• Portable control panel for pressure suit (2 Req'd)<br>• Power source for support of lighting mockup<br>• Simulated launch pad umbilical arm for support of ingress/egress mock-up studies.<br>• Simulated visual presentation for approach, landing, rendezvous & docking in support of mockup studies<br>• Photograph equipment to document mockup studies and reviews |
| Software | • Computer program to implement simulated visual presentation |

TABLE 10.1-3 CREW MOCKUP FACILITY REQUIREMENTS LIST

| Facility | New | Exist. | Contr. | Gov. |
|---|---|---|---|---|
| Note: The orbiter will require a separate room to house the contemplated mockups. As a minimum the 747 technique can be employed whereby half a fuselage is mocked up. The room should be sized to contain this half fuselage and additional detail mockups such as cabin, etc. A room size approximately 175 ft L x 100 ft W X 40 ft H with a local high bay area about 60 ft H. This room to house as a minimum:<br>• 1/2 fuselage mockup<br>• Full size cabin mockup (horizontal & vertical)<br>• Suit room<br>• Closed circuit television display room<br>• Display area, tables, walls, etc<br>• Speaker's platform & audience seating<br>• Guard & receptionist area<br>• Rest rooms<br>• Conference rooms | | X | X | |

## 10.1.2 PAYLOAD INTEGRATION

### 10.1.2.1 Mockups and Models

The primary purpose of a payload integration mockup is to provide preliminary verification of payload interfaces, physical clearances, adequacy of lighting, location of remote sensors and field of view and, to provide a means of mocking up special provisions associated with nonstandard payload modules. These objectives are met without the costs involved in fabricating and maintaining a dedicated full size high-fidelity mockup of the payload area by using scale models, and intermittant use of the structural systems line runs mockup at Grumman.

- Accurate (1/5 scale) models, of the payload bay are used with models of proposed payloads to establish visibility, serviceability, and other interfaces with the orbiter. These models, together with their appropriate ICD's, are provided by NASA to the payload contractors as GFE tools to establish payload compatibility prior to fabrication. Payload support pallets and docking mechanisms in the models are capable of being deployed to provide moving clearance information. The use of several models provides program flexibility since many payloads are under development simultaneously. Models are manufactured from scaled production drawings and are updated to reflect orbiter/payload interfaces. Six models are manufactured; three are delivered to NASA center, and three are delivered to designated payload integrators.

- The structural system line runs mockup described in subsection 10.1.3 is sufficiently accurate to verify the installation of a 15 ft dia by 60 ft payload. This mockup also serves, in conjunction with a soft mockup of special payload modules, to work out unique electrical/fluid or lighting provisions.

### 10.1.2.2 Tools and Test Articles

The program objective to define and develop standardized payload support and docking interfaces is met for most payloads with a standard payload support system. For these payloads, a set of standard hard tools (interface tools) are developed that permit absolute

matching of structural and functional, (i.e., mechanical, electrical and fluid) connections, at any facility manufacturing a payload module. These tools (which include standard electrical power supplies and thermal control interfaces), plus ICD's, verify fit and function prior to delivery of experiments or modules.

Although it is not part of the basic orbiter development, the need for a full-scale test article has been identified in subsection 3.8. Use of this test article decouples payload integration from orbiter manufacture after payload contractors are selected and payload defined in detail. The flight weight test article duplicates the section of the orbiter surrounding the payload and permits final integration of the payload, physically and functionally, including electrical, EMI, and thermal compatibility verification. The test article is used to qualify a stowed payload package for the launch pad, launch and boost and on-orbit environmental conditions, but not including payload deployment, separation or docking operations.

Overall program costs are reduced by using the test article to perform dynamic and acoustical vibration surveys on mass models of proposed payloads to provide designers with accurate environment information prior to fabrication. This reduces payload development costs resulting from over-qualification of components to unrealistically high arbitrary vibration/shock levels and eliminates expensive post-delivery modification by resolving structural dynamic problems during development testing.

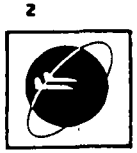
Additionally, the test article resolves these typical problems:

- Control of payload effluents vented into cargo bay
- Payload bay venting
- Purging of payload bay
- Interaction between multiple payload packages
- Payload sensor alignment
- Thermal deflections affecting sensor and control alignments
- Thermal environments with payload doors open and closed

Fig. 10.1-5 Airframe Mockups Schedule







Interface tools, fluid and electrical test stand, instrumentation consoles and the flight weight Payload Integration Test Article are the joint responsibility of NASA/Payload Integrator.

10.1.2.3 Payload Integration Lists

a. Major Components List

- Six accurate 1/5 scale models of payload bay and deployment mechanism (wood and metal construction)

b. Inputs Required

- ICD for payload modules
- Design of selected standard payload support, deployment, retrieval interface

c. Outputs to Other WBS

- ICD's
- Scale model drawings

10.1.3 STRUCTURES, LINES-RUN AND EQUIPMENT INTEGRATION MOCKUP

Equipment Lines Group provides routing paths and space allocations in accordance with system engineering requirements; i.e., maintainability, reliability, safety, etc. To achieve this effectively, a mockup is necessary to define the layouts.

Secondary benefits derived from the mockup are definition of levels of manufacturing difficulty, more accurate cost estimating, establishment of quality standards, inspection sequences, manufacturing crew loading, improved manufacturing methods, maintenance training and customer familiarization.

The full-scale mockup shown in Fig. 10.1-6 will include the entire fuselage with a representative segment of the payload doors, stub sections of the vertical fin and wing, and the crew and payload compartments. The mockup will be constructed of wood, exclusive of congested areas which will be metal or combinations of both wood and metal for the degree of accuracy required and will adequately represent structural module divisions. A simulated air breathing engine deployment and closure door mechanism will be installed on one side of the fuselage. All affected structure and movable hardware will be designed with

sufficient strength and stiffness to satisfy the requirements of the deployment and lock-out cycle of engines and closure doors and to demonstrate relative clearances of all moving parts including plumbing and wiring as applicable. Hydraulics will be used to activate the devices. Portions of the closure doors and their interfaces will be fabricated with representative TPS and seals in sufficient detail to demonstrate function of the interface.

One main landing gear assembly with its closure door mechanism and the nose gear assembly with its closure door mechanism will also be installed. The gear and closure door linkages and supporting structure will be designed with sufficient strength and stiffness to satisfy the requirements of the deployment/stow cycle and to demonstrate relative clearances of all moving parts including plumbing during a cycle. Hydraulics will be used to actuate the system. Portions of the closure door and its interface will be fabricated with representative TPS and seals in sufficient detail to demonstrate function of this interface.

Included in this mockup will be mechanical, fluid, and electrical payload interfaces for verification of physical clearances, adequacy of lighting, fields of view (and viewing sensors if required). Special provisions associated with specific payload modules can be installed and evaluated.

The use of a dimensionally accurate all-metal replica of the flight article as a mockup will be considered as an alternate approach. The objective of this higher fidelity approach would be to use the mockup for fabrication of fluid tube tooling and wire harness boards. In addition, it would serve to verify structural geometry and preliminary assembly procedures prior to assembly of the flight article. This mockup would be constructed entirely of metal, using aluminum in place of titanium and composite structure. The dimensional accuracy required to meet the objective necessitates the use of modified production layouts and/or drawings. The baseline development schedule does not allow sufficient time for this type of mockup to lead the assembly and installation sequences in the first flight vehicle. In the event future changes in the development schedule allow sufficient lead time between layout availability and first vehicle assembly the cost effectiveness tradeoff will become the determining factor.

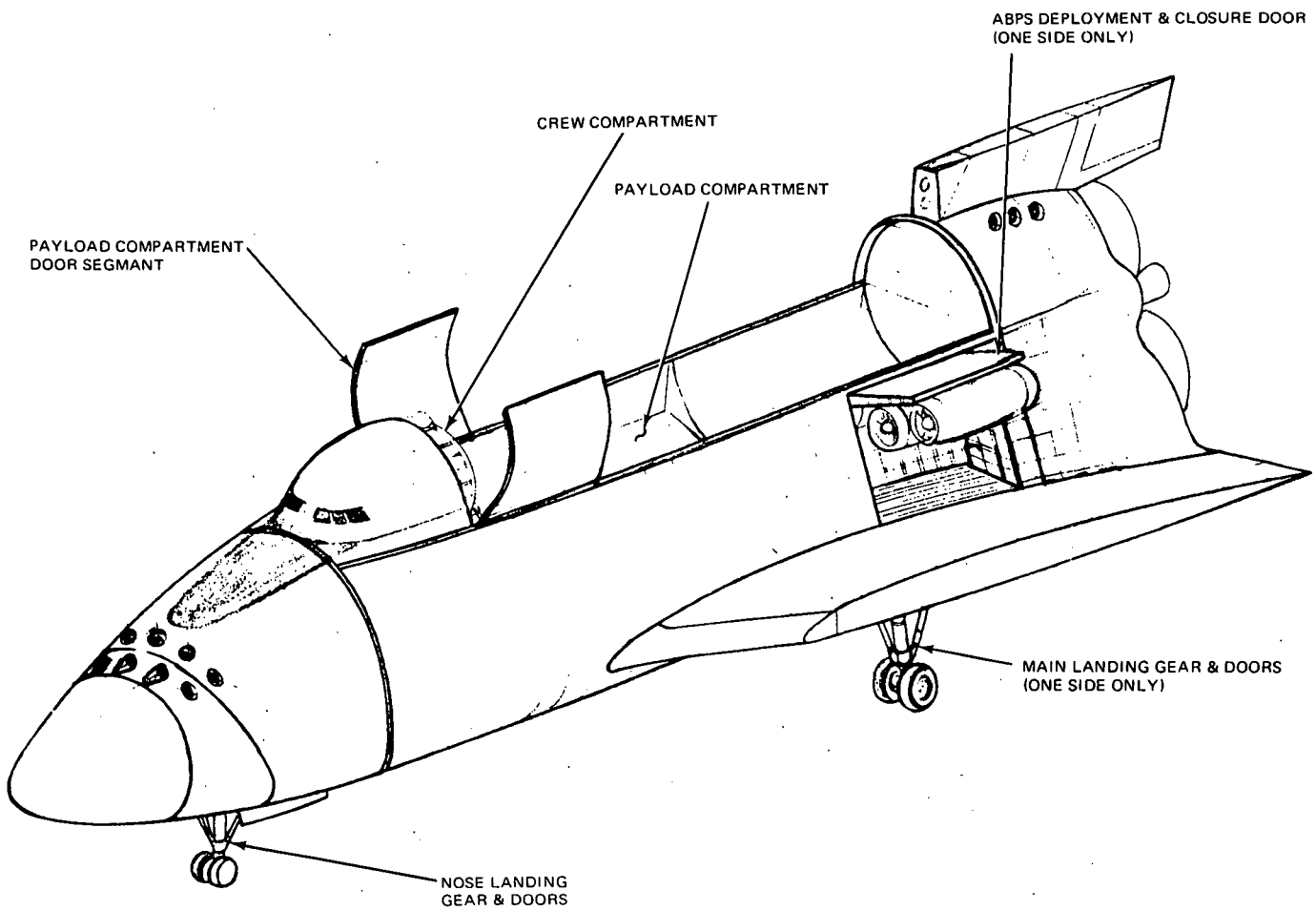



Fig. 10.1-6 Lines-Run and Equipment Integration Mock-Up

## 10.1.4 MAIN PROPULSION/BASE HEAT SHIELD/STRUCTURE MOCKUP

### 10.1.4.1 Purpose

Access, inspection, maintenance and removability methods in both the horizontal and vertical positions will be evaluated by means of a full scale engine compartment mockup.

### 10.1.4.2 Description

This mockup will comprise the aft fuselage structure, the main engines installation, the orbital maneuvering system engines installation plus their auxiliary heat shields and other supporting equipment and installations. Optimum maintenance techniques, support equipment designs and procedures will be determined and demonstrated by trial and error and by repetition. Continuous updating is planned.

### 10.1.4.3 Configuration

This mockup will start approximately at fuselage station 1582 and extend aft. It will have a simulated stub vertical surface, simulated aft ends of external $LH_2$ tanks, plus simulated stub wing sections to assure that the access to the vehicle is properly represented. The mockup will be built representing the orbiter in the normal horizontal ground attitude, except for actual ground clearance. In addition, the mockup will be capable of being rotated to the vertical "on pad" attitude to insure necessary "on pad" maintenance and inspection access plus the development of the necessary tools and techniques. The initial version will be constructed of wood with the equipment represented by space envelopes. As the flight weight structure is designed, true scale metal parts will replace wood. Likewise, as the design of each piece of equipment becomes more finite, the space envelopes will be replaced by detailed wooden, and finally, metal mockups to that equipment relationships, as they will exist in the flight vehicle, are depicted. Each equipment mockup will be installed so that clearances, access for servicing, repair, removal and replacement will be verified for the appropriate vehicle operational sequences. The logic and schedule of the mockup are shown in Fig. 10.1-8 and 10.1-5.

### 10.1.4.5 Location

This mockup can be located in the LM final assembly high bay area in Plant 5 at Bethpage. This area has a ceiling clearance of 36 ft 4 in. and hook heights of 27 ft 10 in. or 30 ft 9 in.

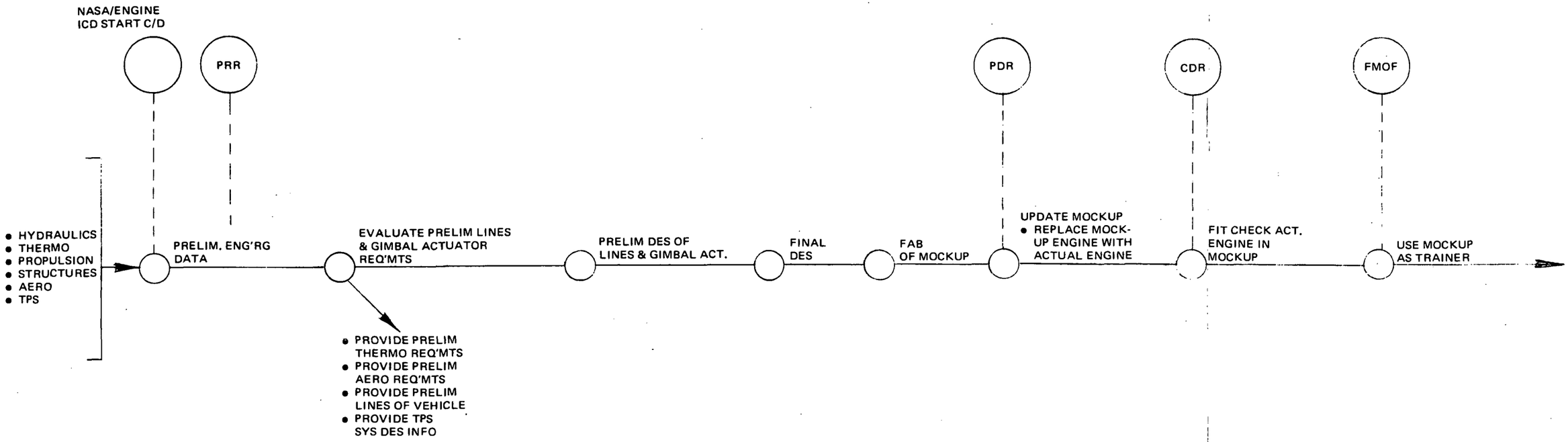





Fig. 10.1-7 Main Propulsion Base Heat Shield Structure Mock Up Logic Chart

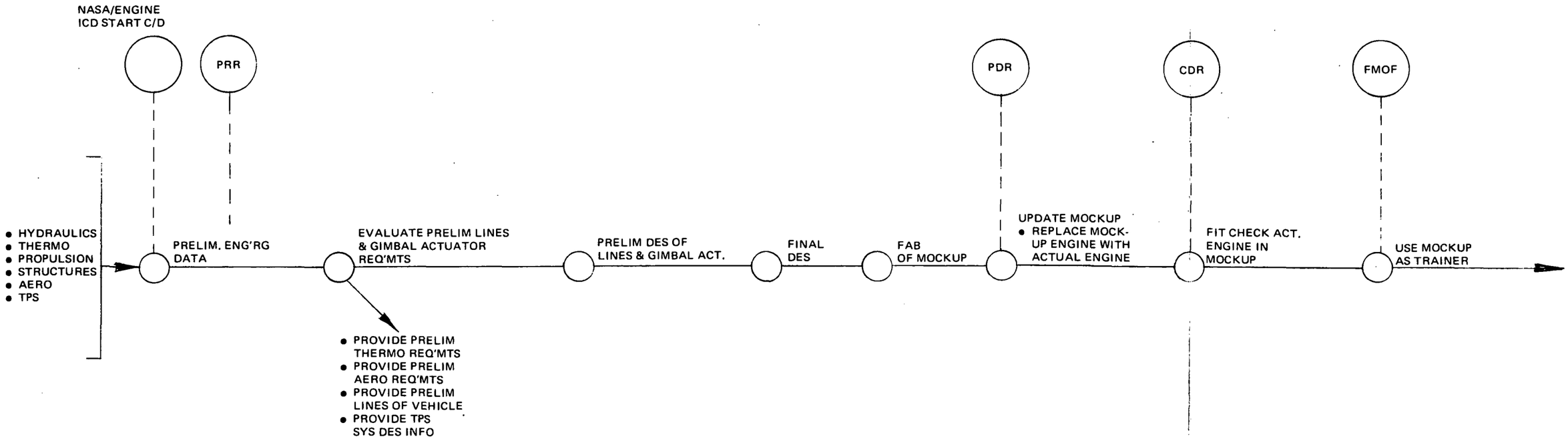





Fig. 10.1-8 Main Propulsion Base Heat Shield Structure Mock Up Logic Chart



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# 10.2 STRUCTURAL TEST ARTICLE

## 10.2.1 INTRODUCTION

In formulating a program for structural integrity testing of the orbiter, consideration is given to both verification of structural adequacy and demonstration of safe-life.

The structural design of the orbiter is such that the thermal stresses induced in the primary structure are maintained at low levels through the use of a thermal protection system (TPS). The TPS ensures that the temperature of the basic structure will never exceed the design allowable which is presently set at 600°F.

## 10.2.2 TEST ARTICLE CONFIGURATION

The test program is conducted on a single structural test article (STA) which consists of basic structure without TPS. It includes fuselage, left and right hand wing, fin, rudder and left hand elevons, left hand engine mounts and all tank supports but not tanks. Directional (rudder) and left wing flight controls without actuators are also included. An assembled test article results in a more economical program and in a higher order of confidence in the test results. For example, interaction problems such as the treatment of the indeterminant wing-to-fuselage connection are avoided while at the same time the cost of separate test fixtures is avoided.

## 10.2.3 DESCRIPTION OF THE TEST PROGRAM

Since a single test article is used for both static strength and fatigue testing, the test article and test fixtures are configured for a series of critical design conditions. Tests are first run in a static test, incremental loading, mode for each critical condition within the spectrum to provide strain/deflection data. Peak loads and temperature levels are applied to a level sufficient to qualify the orbiter for the required flight conditions. The test set-up is then PROGRAMMED for repeated load/temperature spectrum tests. Schedule considerations permitting, load/temperature cycling is continued for the full 400 mission life demonstration (100 missions times a scatter factor of 4). Initial schedule

studies indicate that the orbiter can be cleared both for maximum loads and life prior to the first manned orbital flight (FMOF).

A four phase program has evolved to structurally qualify the orbiter. This program is planned to clear the airframe for critical milestones in the flight test program and to accomplish testing economically with respect to facilities and test equipment considerations. The STA program schedule is presented in Fig. 10.2-2.

- Phase I - Items Tested Prior to Assembly to the Structural Article - Because of the special nature of some of the tests, certain components or assemblies are tested prior to assembly into the STA. Typical examples of this would be the crew/passenger compartment which is pressure tested prior to mating with the fuselage mid-module. An elevated temperature windshield test and the seat support structure test may also be performed on this subassembly. Hot structure-components requiring high temperature testing are also tested off the STA. The question of real time temperature testing relative to steady state (soak) temperature tests is discussed in paragraph 10.2.4.

- Phase II - Items Tested on the Article and Tests of Locally Critical Structure - During the period the test article and the test fixture and loading apparatus for major design conditions are being erected the following tests are run:

  - Main and Nose Landing Gear and Support Structure
  - Drag Chute and Chute Jettison Mechanism
  - Control Surfaces
  - Control Operating Systems
  - Doors, Hatches and Access Panels
  - Payload Retention System
  - (Air Breathing Engines) Supports and Deployment Mechanism
  - Payload Deployment Mechanism and Supporting Structure

- Phase III - Tests for Major Critical Conditions - The critical design conditions in the orbiter mission profile occur primarily during first and second stage boost, reentry and subsequent pull-up. A fatigue load/temperature spectrum is derived for the critical design condition and serves as the basis for the requirements of this phase. Two basic test configurations are used to qualify the structure for:

  - Vertical Flight Conditions
  - Critical Reentry and Horizontal Flight Conditions

The use of a computer controlled load servo system enables all conditions to be tested with no mechanical rerigging between tests. Tests are run in both the static mode (incremental loading to obtain stress/strain distribution and deflection data) and in the repeated loads (fatigue) mode. Tests methods for elevated temperature tests simulating reentry and subsequent maneuvers with the primary structure hot are to heat the structure relatively slowly, maintaining appropriate constant temperature plateaus for sufficient time to accumulate the required cycles for that block and condition. Thus if the 100 x 4 mission life is simulated in say 20 blocks only 20 temperature-cycles are applied but 40 cycles of load at the required levels are applied at each temperature level. It is estimated that using this method the accumulated time at temperature on test approximately equals the time at temperature on actual missions.

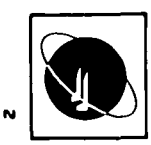
- Phase IV - Failure Modes Demonstration - In this phase of the program a series of tests to demonstrate the failure modes and reserve margin of the airframe are conducted. The fatigue loading will be continued until failure occurs or the static load will be increased to determine the strength margin remaining after the fatigue life demonstration is completed.

### 10.2.4 TESTING FOR THERMAL STRESSES

Testing is required for components or local structural areas where stresses or structural distortion due to thermal effects are significant. Temperature soak tests do not simulate the real-time temperature environment seen by the vehicle structure but only introduce effects due essentially to the reduction of material properties. Transient temperature tests in which the true load-temperature history of a structure is simulated produces the temperature gradients within the structure and hence the correct induced thermal stresses. Accurate superposition of the flight loads then theoretically produces a fully







representative test under the critical thermal/mechanical stress environment. However, tests of this nature on the overall static test article are not proposed since the test set-up would be extremely complex and would have a development risk in addition to requiring costly facilities. We believe that the structural integrity of the orbiter can be best demonstrated by more nearly standard static and fatigue test programs with selective application of temperature effects only where required by the analysis.

10.2.5 CERTIFICATION REQUIREMENTS

The orbiter primary structure (fuselage and aero-surfaces) is certified by a combination of analysis, component testing, and tests conducted on the STA. Certification of the TPS and cryo-tankage (internal and external) is not included in the STA program but is described in subsections 3.2, 3.3 and 3.4 of this volume.

The criteria for the structural certification of the aerodynamic surfaces are:

- Static strength and stiffness are verified by a combination of analyses and proof tests (design limit load times a factor of 1.0 or greater)
- Fatigue life is verified by spectrum cycling tests for 100 missions times a scatter factor of 4.0
- Operation of moveable control surfaces is verified after application of the proof load
- Failing tests are performed selectively to verify the failing margins and modes

The criteria for the structural certification of the fuselage and tank support structure are:

- Static strength and stiffness are verified by a combination of analyses and proof tests (design limit load times a factor of 1.0 or greater)
- Fatigue life is verified by spectrum cycling tests in combination with the wing and tail tests above
- The strength, life and leakage characteristics of the pressurized crew and passenger compartments are verified by repeated pressurization to the maximum relief pressure for 100 missions times a TBD scatter factor

- Operation of mechanisms and doors are verified after application of the proof loads or pressure
- Failing tests are performed selectively to verify failing margins and modes

10.2.6 SUPPORT EQUIPMENT AND FACILITY REQUIREMENTS

The test support equipment and facilities needed to perform the structural tests on the STA are summarized in the tables at the end of this section.

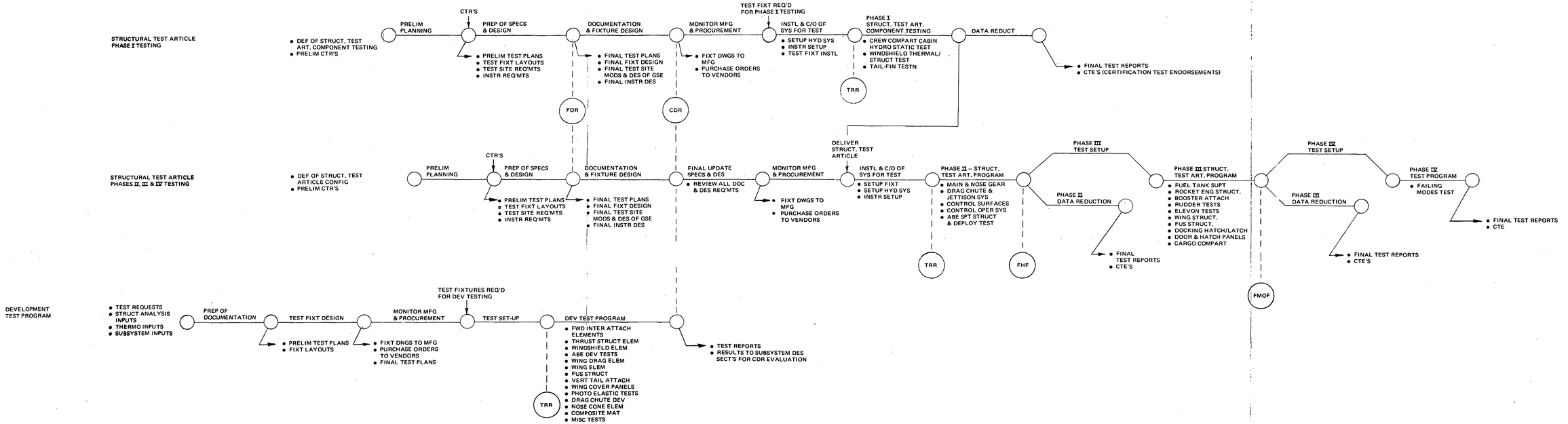



Fig. 10.2-1 Structural Test Article Logic Network



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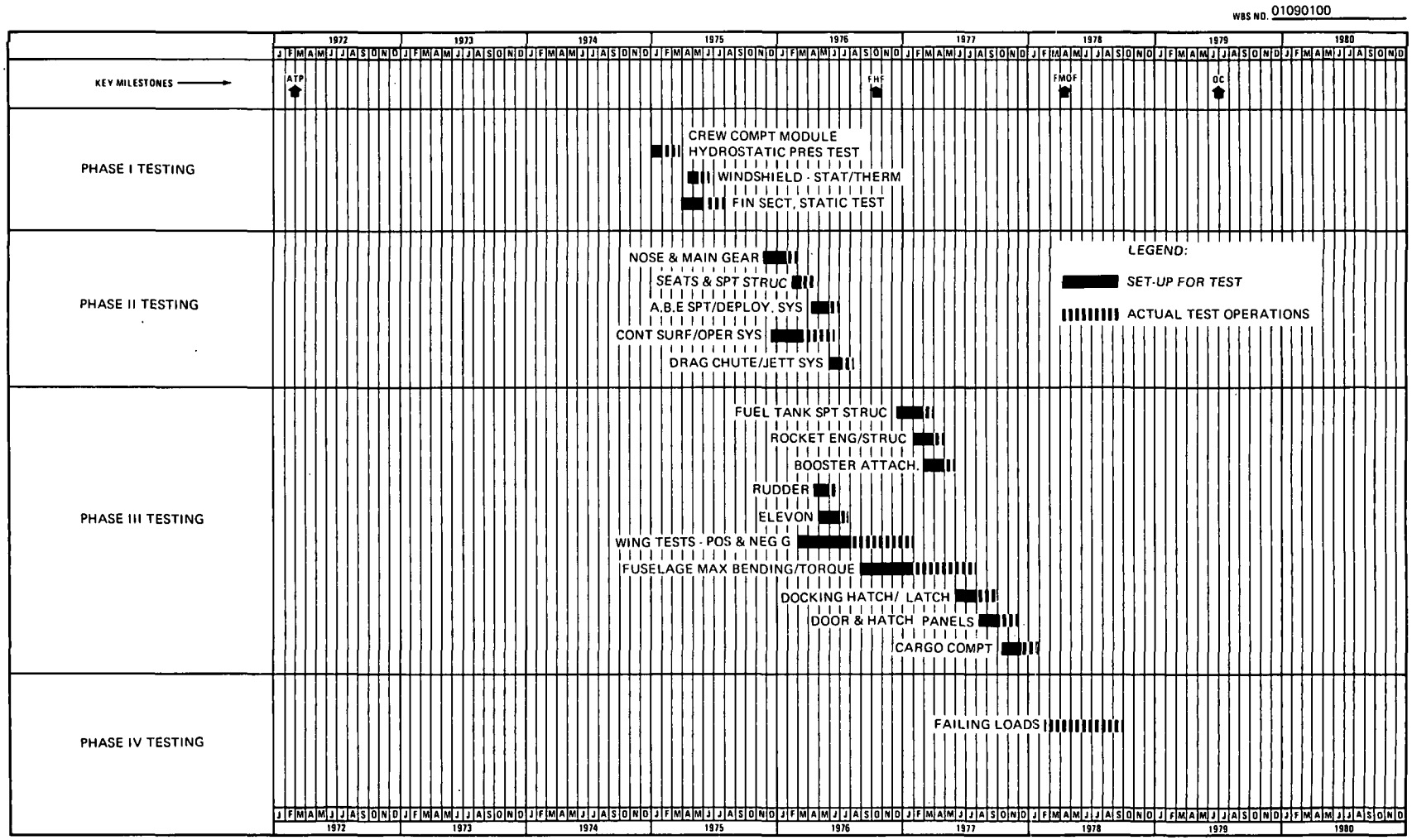


Fig. 10.2-2 Development/Verification Test/Structural Test Article Schedule

TABLE 10.2-1. CERTIFICATION REQUIREMENTS
(Sheet 1 of 2)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Test Vehicle |
| • Wing Outer Panel | X | | | | X | | X | | | | X |
| • Wing/Fuselage Attachment and/or Carry Thru | X | | | | X | | X | | | | X |
| (Certify for Strength, Stiffness, Safe Life and/or Fail Safe Requirements) | | | | | | | | | | | |
| • Elevon | X | | | | | X | X | | | | |
| • Elevon Attachments and Operating System | X | | | | | X | | | | | X |
| • Vertical Fin | X | | | | | X | X | | | | |
| • Fin Attachment | X | | | | | X | | | | | X |
| • Rudder | X | | | | | X | X | | | | |
| • Rudder Attachments and Operating System | X | | | | | X | | | | | X |

TABLE 10.2-1. CERTIFICATION REQUIREMENTS
(Sheet 2 of 2)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Test Vehicle |
| Basic Fuselage (Max. Bending) | X | | | | | X | | | | | X |
| (Max. Torsion) | X | | | | | X | | | | | X |
| Crew and Passenger Cabin Press Test | X | | | | | X | | X | | | |
| Windshield | X | | | | | | | X | | | |
| Engine Mounts (ABPS) | X | | | | | X | | | | | X |
| Engine Mounts (Boost) | X | | | | | X | | | | | X |
| Tank Mounts (Int & Ext) | X | | | | | X | | | | | X |
| Cargo Doors & Operating Mechanism | X | | | | | X | | | | | X |
| Doors, Hatches, Access Panels | X | | | | | X | | X | | | X |
| Cargo Retention System | X | | | | | X | | X | | | X |
| Crew & Passenger Seat Tie Downs | X | | | | | X | | X | | | |
| Drag Chute Attachment | X | | | | | X | | | | | X |
| Interstage Connections | X | | | | | X | | | | | X |

NOTE - Internal and External Tanks and Thermal Protection System Will Be Separately Certified. See subsections 3.2, 3.3, and 3.4

TABLE 10.2-2 SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | Two bucket trucks with 60 ft arms<br>300 channel fatigue test controller<br>20 channel power controller<br>500 load actuators<br>500 load links<br>25 TV cameras and monitors with tape system<br>Thermal reflectance shroud<br>Quartz lamps and reflectors<br>2000 channel data acquisition system<br>X-ray inspection equipment<br>Eddy current inspection equipment<br>Zyglo inspection equipment<br>Krypton crack detector inspection equipment<br>1000 linear displacement transducers, range 1/2 in. to 10 ft |
| Software | Programs for:<br>Load Control<br>Data Acquisition<br>Data Reduction |
| | |

TABLE 10.2-3. STRUCTURAL TEST ARTICLE PROGRAM
FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr | Govt |
|---|---|---|---|---|
| • Reinforced test floor 250 x 150 ft in high bay area with 80 ft minimum clearance under crane hook. The floor structure to be capable reacting 300 x $10^6$ in-lb moment and concentrated loads up to 200 kips. Floor construction may be either reinforced concrete or welded steel. Area to be served with one 100-ton crane or 2 50-ton cranes | X | | | X |
| • Support area, 100 x 100 x 30 ft high area for test fixture fabrication. Area to be adjacent or have easy access to test area and be served with 10-ton crane | X | | | X |
| • Test and support area to be serviced with normal shop requirements. | | | | |
| - Power 110, 220 and 440 V electrical service | X | | | X |
| - Compressed air 90 psi, 1000 cfm | | | | |
| - Hydraulic 3000 psi, 1200 gpm | | | | |
| • Test area to be equipped with blower system to exhaust high temperature air and special fire detection and suppression equipment | | | | |
| • Test frame 150 x 100 x 60 ft high to react applied loads. Frame to be equipped with work platforms at appropriate level and two service elevators | X | | | X |
| • Power (for elevated temperature test), 10 megawatts continuously rated, 440 volts | X | | | X |

# 10.3 PROPULSION TEST ARTICLE PROGRAM

## 10.3.1 INTRODUCTION

The Propulsion Test Article (PTA) is a flight-weight structure containing the complete Main Propulsion System (MPS) and those portions of the other subsystems needed to support the functioning of the MPS. After completion of the test program the PTA is converted to flight status as the fourth orbiter by the addition of the forward fuselage station, wings, TPS and all equipment and lines not originally installed. The configuration of the PTA prior to its conversion is summarized in Table 10.3-1.

The timely verification of critical dynamic and thermal interactions between the MPS and its supporting and surrounding structure are the major factors requiring a flight-weight test article. The vibration mode shapes and frequencies of the tank shells and the supports of the tanks, lines and engines have an important influence on the performance and life of the system and its Pogo sensitivity. The heat transfer factors governing filling rates, stratification, geysering and prestart engine conditioning characteristics also require flight-weight structure for valid verification. Due to the unique removability feature of the H-33 orbiter $LH_2$ and $LO_2$ tanks, this flight-weight test article can be completely inspected and safely converted to flight status after completion of the test program thereby providing early test results while eliminating the cost of a dedicated test article.

## 10.3.2 CERTIFICATION TEST REQUIREMENTS

The PTA program provides the primary means of certification of the MPS and is a constraint on the First Manned Orbital Flight (FMOF). This test program integrates the engines and feed system and evaluates both nominal and off-nominal characteristics such as engine-out performance that cannot be verified in flight. The certification test requirements are defined in Table 10.3-2 and are referenced in Fig. 10.3-3, "Test Program Run/ Objective Summary."

Those tests related to verifying filling and checkout procedures are accomplished during cold flow testing. Engine simulators are used and flight-weight $LH_2$ tanks are needed only for those tests evaluating thermal performance or dynamic response. In the latter case the feed system compliance is surveyed over the critical range of frequencies using pulsed-flow techniques to verify the Pogo analysis. Mission duration cold flow tests are also performed to evaluate propellant management and to verify the uniform emptying of the dual tanks.

The hot firing phase of the PTA program evaluates the performance and the start-up and shut-down thrust characteristics of the three engine installation and also for the engine-out combinations. These tests verify the capability of the three-engine H-33 orbiter to continue its design mission with one engine out. These test objectives can be satisfied without mission duration firings and each test will be terminated after steady-state conditions are reached for consideration of schedule and cost.

### 10.3.3 PTA PROGRAM DESCRIPTION

The program is estimated to require a period of one year from the start of cold flow testing to the completion of the hot firings. Refer to the Test Logic Network of Fig. 10.3-1, overall schedule in Fig. 10.3-2 and test schedule in Fig. 10.3-3.

The PTA is mounted vertically to support its dead weight with full tanks during cold flow tests and to react the thrust of the engines during hot firing with almost empty tanks. Corrections will be made to account for the differences in pump inlet pressures between the one g test condition and the actual flight acceleration profile. The PTA program is discussed in relation to the total propulsion development program in Subsection 4.1 of this volume.

### 10.3.4 TEST FACILITIES

The PTA program may be conducted at either the Mississippi Test Facility (MTF) or at the launch site at KSC. A summary of the facility requirements is provided in Table 10.3-3, and a complete discussion of the facility options is presented in the Facilities Plan.

TABLE 10.3-1. PROPULSION TEST ARTICLE CONFIGURATION

| Subsystems | MPS | Structure | Avionics | Displays & Controls | Power |
|---|---|---|---|---|---|
| Major Components and Assemblies | • Propellant Feed<br>• Pressurization Sys<br>• Tank Purge System<br>• Engine Simulators (Cold Flow Only)<br>• Engines (Hot Firing Only)<br>• LOX Tankage (Flight-Weight)<br>• $LH_2$ Tankage (Heavy-Weight)<br>• $LH_2$ Tankage (Flight-Weight for Vibration Survey)<br>Pneumatic System | • Mid-Module<br>• Aft Module (Incl Engine Compt)<br>• Heat Shield<br>• Acoustic Shroud (Heavy-Weight)<br>• Interface Support Structure | • Thrust Vector Controls (Partial - only, Components directly interfacing with engine umbilical)<br>• Power Bus (Partial or STE)<br>• Onboard Checkout Equipment (Partial - only MPS Components) | • MPS Transducers (Flight + STE)<br>• Signal Conditioners (Flight + STE) | • Hydraulic Sys<br>• APU, if req'd |



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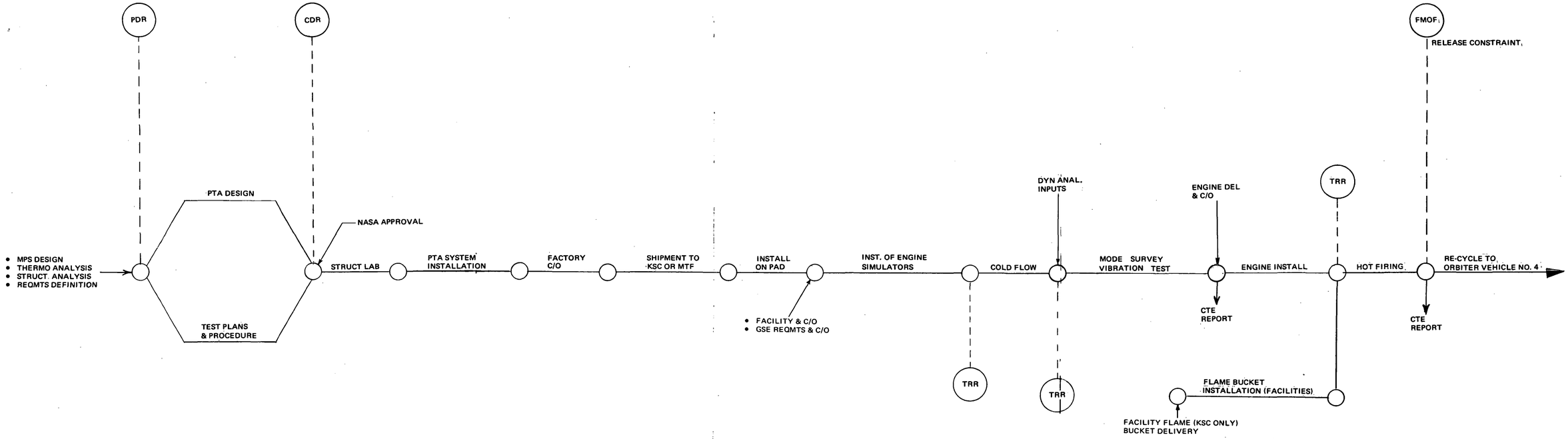


Fig. 10.3-1 Propulsion Test Article Logic Network



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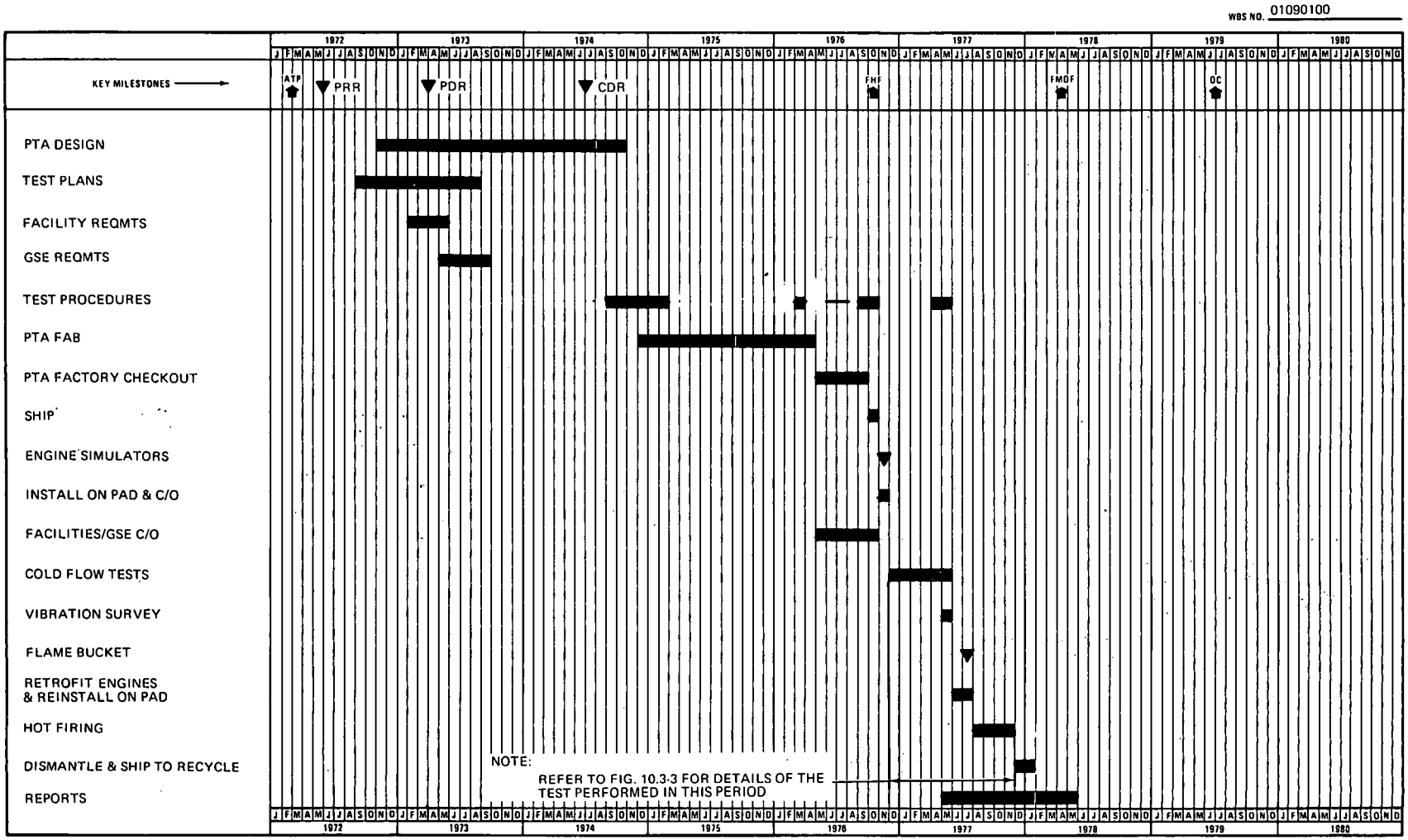

Fig. 10.3-2 Systems Test/Propulsion Test Article Schedule

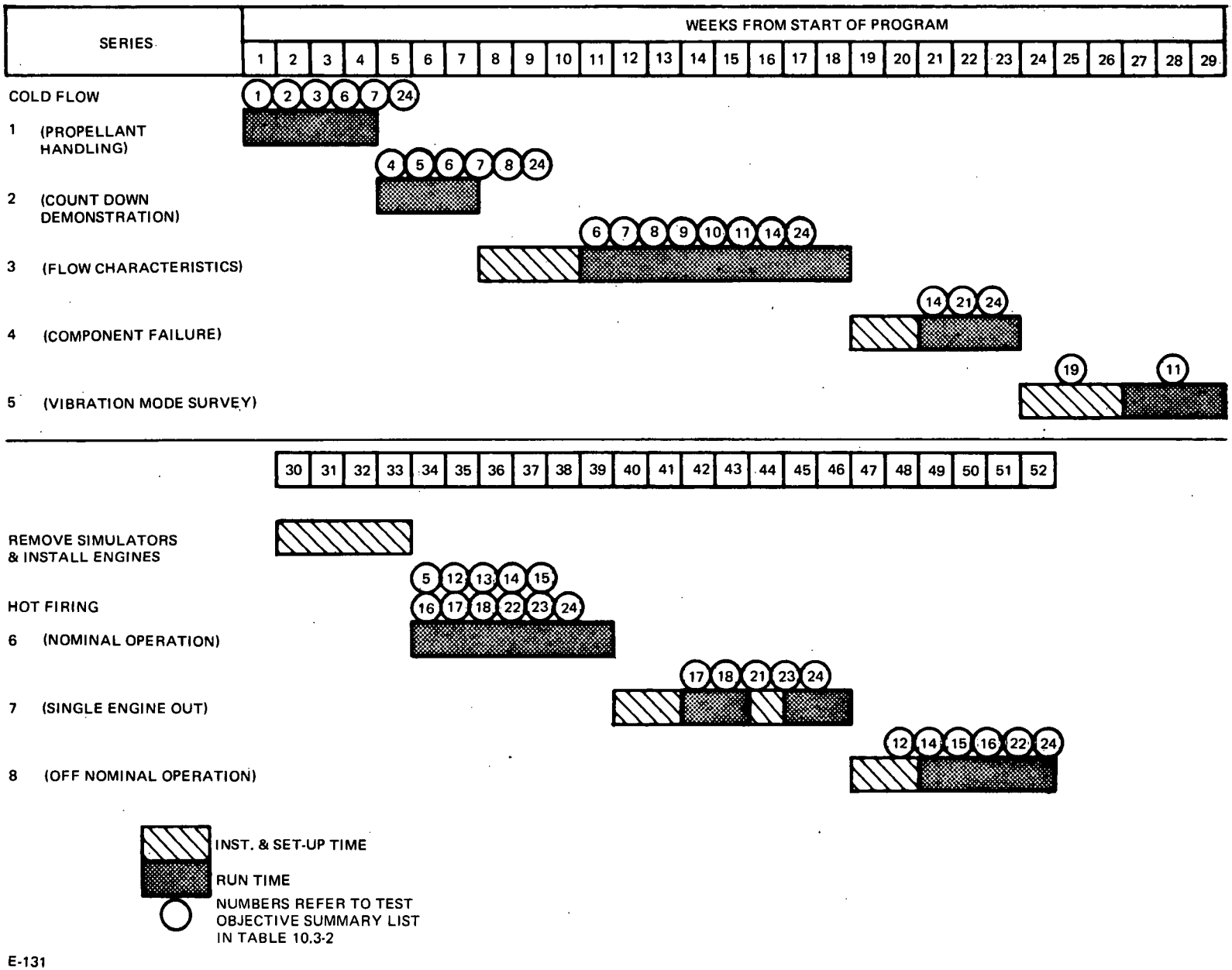


Fig. 10.3-3 PTA Test Program Run/Objective Summary

TABLE 10.3-2 CERTIFICATION TEST REQUIREMENTS
(Sheet 1 of 2)

| Ref. No. | Test Requirements | Phase I Cold-Flow | Phase II Static Firing |
|---|---|---|---|
| 1. | Develop operational C/O procedures & techniques using onboard C/O equipment & RF support links | X | |
| 2. | Demonstrate ability to perform leak tests of fluid systems (accessibility at launch site | X | |
| 3. | Demonstrate dumping, purging & inerting of tanks | X | |
| 4. | Perform countdown demonstration using onboard C/O equipment (including pad Hold) | X | |
| 5. | Evaluation of flight transducer performance and location | | X |
| 6. | Demonstrate propellant loading control & accuracy | X | |
| 7. | Evaluate effectiveness of $LH_2$ tank thermal insulation | X | |
| 8. | Demonstrate external inert gas purge technique to limit ice formation | X | |
| 9. | Verify propellant flow characteristics & feed system pressure drops while discharging at tanks emergency, normal, and minimum power level flow rates (using engine simulators) | X | |
| 10. | Verify passive propellant management capability | X | |
| 11. | Obtain feed system/dynamic response to support Pogo Analysis | X | |
| 12. | Demonstrate complete subsystem operation (including propellant feed and pressurization system, vehicle elect. power and onboard C/O and monitoring systems, hydraulic power subsystem with main engines) | | X |
| 13. | Determine engine start-stop transients when coupled with vehicle control & feed system | | X |
| 14. | Verify proper propellant conditions at engine inlet throughout transient and steady state conditions | | X |
| 15. | Verify performance of TVC system when coupled with simulated hydraulic power source | | X |
| 16. | Verify operation of engine conditioning & recirculation system | | X |

TABLE 10.3-2 CERTIFICATION TEST REQUIREMENTS
(Sheet 2 of 2)

| Ref. No. | Test Requirements | Phase I Cold-Flow | Phase II Static Firing |
|---|---|---|---|
| 17. | Evaluate engine thrust mount/vehicle structural compatibility; determine vibration environment and load paths during engine operation | | X |
| 18. | Demonstrate cluster engine servicing & accessability at launch site | | X |
| 19. | Demonstrate $LH_2$ tank removal and installation | X | |
| 20. | Demonstrate single engine out/EPL operation | | X |
| 21. | Demonstrate critical component failure modes | X | |
| 22. | Demonstrate satisfactory automatic fuel depletion cut-off | | X |
| 23. | Demonstrate propellant utilization under normal and one engine out mode | | X |
| 24. | Demonstrate pneumatic system operation for propulsion components | X | |

TABLE 10.3-3 PROPULSION TEST ARTICLE
FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist | Contr | Gov |
|---|---|---|---|---|
| Modified Firing Stand or Launch Pad & Control Facility (Including On pad Erector | | X | | X |
| Assembly Facility (For Tank & Engine Retrofit) | | X | | X |
| Umbilical Tower (KSC Only) | X | | X | |
| PTA Support Structure (Simulated Booster) | X | | X | |
| Flame Bucket (KSC Only) | X | | X | |



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### 10.3.5 COMPUTER SUPPORT REQUIREMENTS

Refer to subsection 4.1 for detailed software requirements.

# 10.4 CREW ESCAPE SYSTEM TEST PROGRAM

## 10.4.1 INTRODUCTION

A crew escape system is provided for the flight crew of orbiter test vehicles. This system augments the nominal crew accommodations within the crew compartment with an emergency escape capability, and comprises ejection seats as well as a system for providing an egress path.

The system provides for escape from potential blast hazards in the vertical attitude at launch, escape in a horizontal attitude at speeds from 0 to 600 knots equivalent air speed (KEAS), escape from a sea-level pressurized cabin at very high altitude (100,000 ft), escape from the vertical launch attitude during acceleration, and clearance of unusually large tail section.

The escape system is certified through a combination of analysis, similarity and test. Performance data obtained from the demonstration tests on the Grumman EA-6B system, which is identical to this system for the first 0.5 seconds of the seat-rocket sequence, is used. The remainder of the escape sequence is theoretically analyzed for performance capability, augmented by the baseline demonstration test program and test options described below. (Each additional test option phase performed increases the confidence level of system performance.)

## 10.4.2 BASELINE SYSTEM TEST PROGRAM

The baseline demonstration test program consists of:

- Static ejection test in the vertical mode of vehicle orientation (from a tower) to verify crew escape capability prior to launch
- Environmental tests to verify the system's viability after exposure to adverse conditions (sand and dust, salt spray, humidity, heat, cold, sunshine, etc.)

### 10.4.3 BASELINE CREW ESCAPE SYSTEM TEST FIXTURE

If the baseline test program is the only crew escape system test program to be implemented, then a baseline crew escape system test fixture is used. This fixture provides adequate structural support for the seats as well as hatches with their own immediate and inherent frames. It also supports and contains the sequencing system and hatch jettisoning system. High-speed motion picture equipment is also installed. The environmental tests are performed in appropriate conditions and using appropriate equipment.

### 10.4.4 OPTIONAL SYSTEMS TEST PROGRAM

For the other options under study, a comprehensive test program, culminating in a series of full systems ground test, and using a crew escape test fixture as described in 10.4.5 below, would be necessary to demonstrate that the escape system meets all the established performance requirements within the defined escape envelope. These full systems tests include the following phases:

- Static ejection tests (zero altitude/zero velocity) in the horizontal mode of vehicle orientation to verify crew escape capability on the landing strip
- Dynamic ejection tests at various horizontal velocities and accelerations within the escape envelope to verify crew escape capability during flight

The performance of the escape system in the low altitude vertical acceleration region of the mission profile (immediately after launch) is investigated analytically by use of the data acquired during the vertical zero/zero and the horizontal acceleration tests.

### 10.4.5 CREW ESCAPE SYSTEM TEST FIXTURE

If a comprehensive test program (which includes the optional Systems Test Program either wholly or in part) is selected, then a crew escape system test fixture is used to support all full systems ground tests (both baseline and optional) of the crew escape system. This fixture comprises a structure representative of the crew compartment (upper fuselage section) of the orbiter. The crew compartment contains the sequencing system, hatch jettisoning system, and ejection seats, as well as onboard high-speed motion picture equipment. The environmental tests are performed using this fixture, with appropriate support equipment, as a self-contained chamber.

For the dynamic test option, the fixture is mounted on a high-speed rocket-propelled test sled undercarriage, and onboard telemetry and instrumentation is added.

10.4.6 CANDIDATE TEST SITES

The baseline environmental tests are conducted at the GAC Calverton Facility; the static vertical tests at Ranesburg Wash Range, Naval Weapons Center (NWC) or Hurricane Mesa.

The optional static horizontal tests are conducted at Calverton or N.W.C.; the optional dynamic tests at N.W.C. or Holloman AFB.

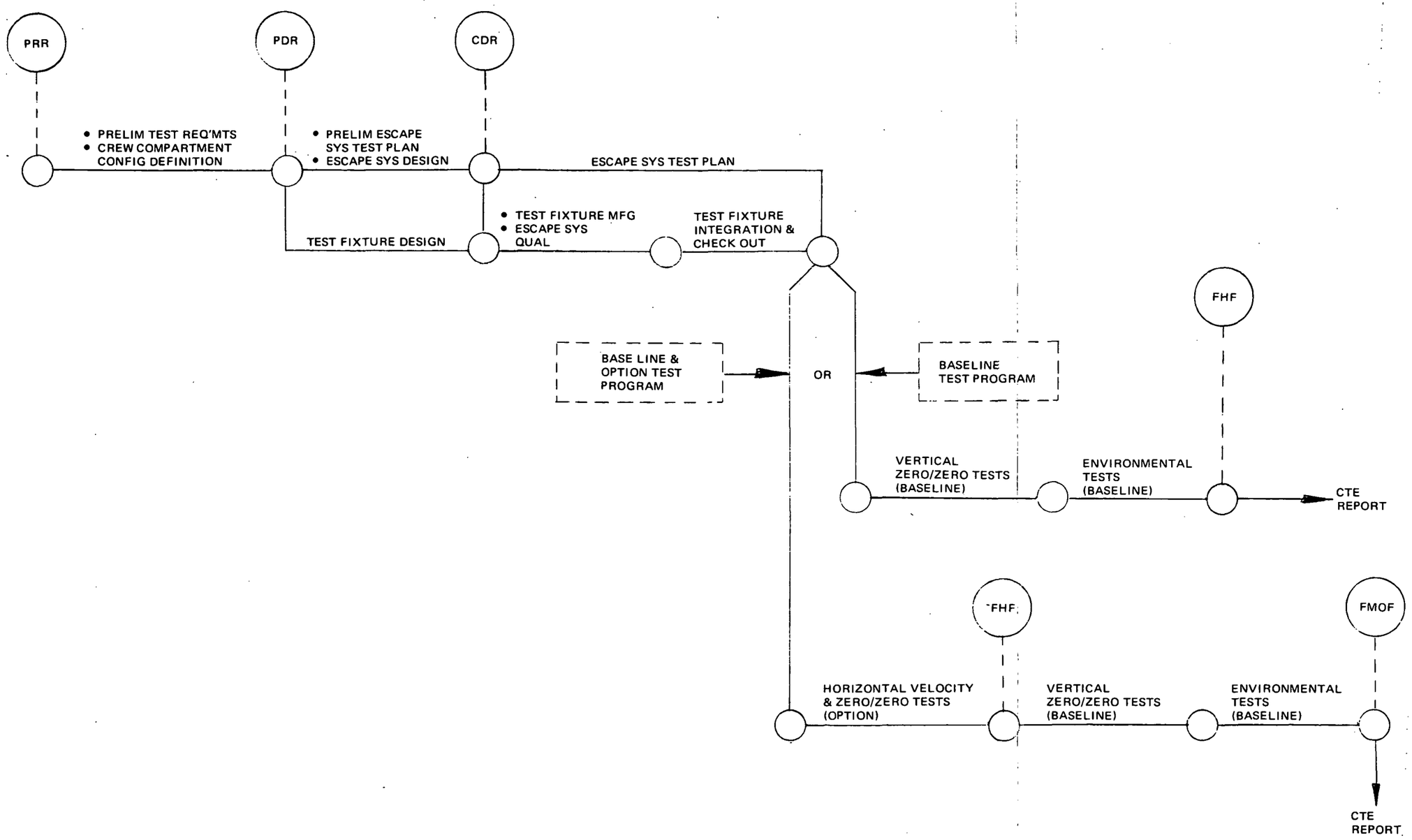


Fig. 10.4-1 Crew Escape System Test Program Logic

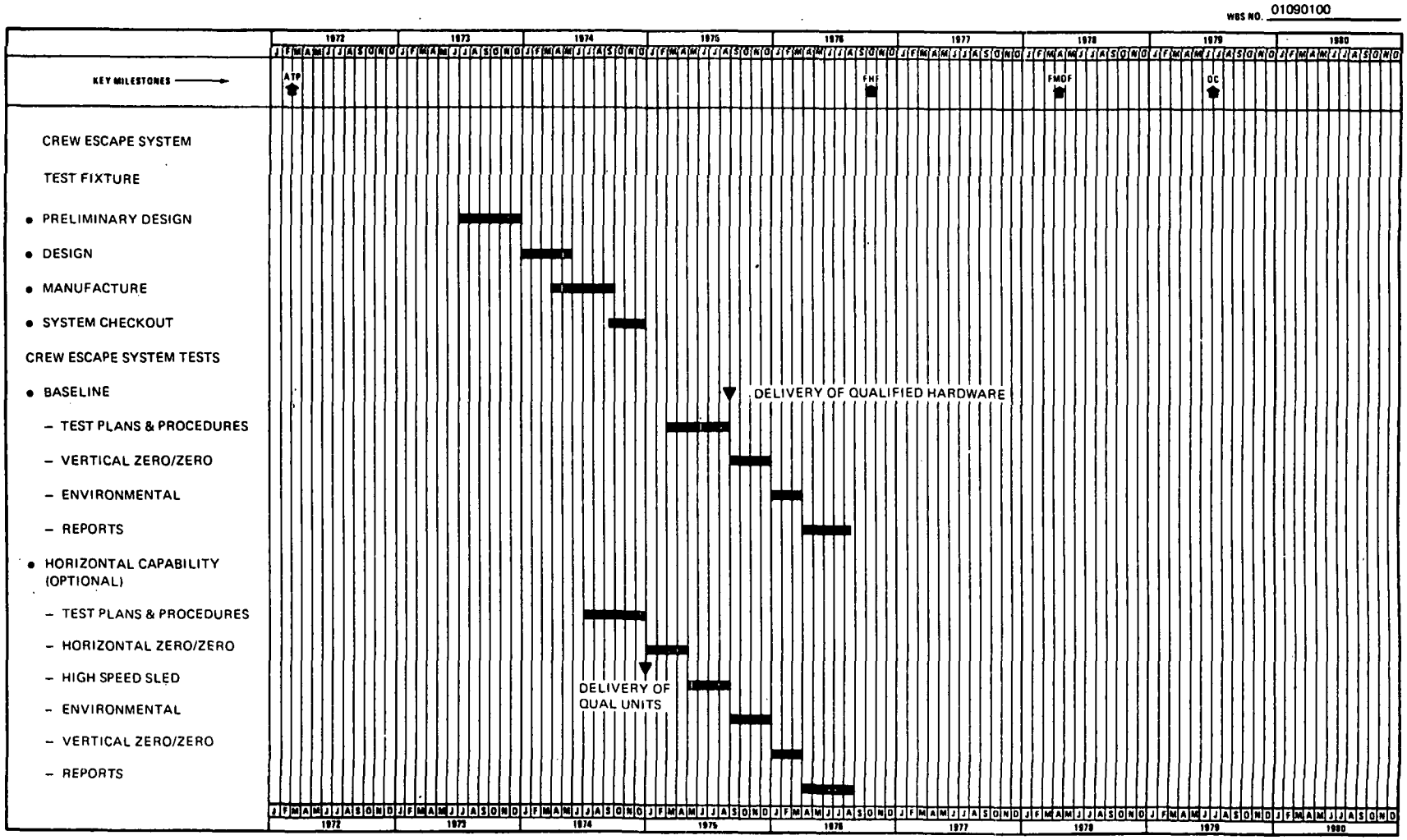


Fig. 10.4-2 Crew Escape System Test Schedule

TABLE 10.4-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| Baseline System | | | | | | | | | | | |
| • Correct operation of crew escape system (i.e., sequencing system, hatch release and jettison system, seat ejection system) from system initiation to recovery of crewmen (i.e., anthropomorphic dummies) in the static vertical (launch) attitude | X | | | | | X | | | X | | |
| • Correct operation of crew escape system (see above) from system initiation to recovery of crewmen in the horizontal attitude and throughout the specified escape envelope | X | | X | | | | | | | | |
| • Adequacy of crew escape system to provide safe rescue for entire range of potential crew percentiles in the static vertical (launch) attitude | X | | | | | X | | | X | | |
| • Adequacy of crew escape system to provide safe rescue for entire range of potential crew percentiles throughout the specified escape envelope | X | | X | | | | | | | | |
| • Capability of crew escape system to extract crewmen safely from potential blast hazard with vehicle in the vertical (launch) attitude | X | | | | | X | | | X | | |

TABLE 10.4-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Maintenance of structural integrity of crew escape system and components during operation in the static vertical attitude | X | | | | | X | | | X | | |
| • Maintenance of structural integrity of crew escape system and components during operation within the specified escape envelope | X | | X | | | | | | | | |
| • Effective operability of crew escape system after exposure to all anticipated environmental conditions (sand and dust, salt spray, humidity, etc.) followed by high, low, and ambient temperatures | X | | | | | X | | | X | | |
| • Capability of crew escape system to protect crewmen from collision or entanglement during escape | X | | X | | | | | | | | |
| Horizontal Capability Option | | | | | | | | | | | |
| • Correct operation of crew escape system (i.e., sequencing system, hatch release and jettison system, seat ejection system) from system initiation to recovery of crewmen (i.e., anthropomorphic dummies) | X | | | | | X | | | X | | |
| • Adequacy of crew escape system to provide safe rescue for entire range of potential crew percentiles throughout the specified escape envelope | X | | | | | X | | | X | | |

TABLE 10.4-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 3)

| Certification Requirement | Certification Method | | | | | | Level of Assembly | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Test | | | | | | |
| | Analysis | Simulation | Similarity | Common Usage | DVT | Qual | Component | Assembly | Subsystem | Comb. Subsystem | Flight Vehicle |
| • Capability of crew escape system to extract crewmen safely from potential blast hazard with vehicle in the vertical (launch) attitude | X | | | | | X | | | X | | |
| • Maintenance of structural integrity of crew escape system and components during operation within the specified escape envelope | X | | | | | X | | | X | | |
| • Capability of crew escape system to protect crewmen from collision or entanglement during escape | X | | | | | X | | | X | | |
| • Effective operability of crew escape system from pressurized cabin at high altitude (high cabin-to-ambient pressure differential) | X | | | | | X | | | X | | |

TABLE 10.4-2. SUBSYSTEM SUPPORT EQUIPMENT/ SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | Sled Dolly<br>Sled Lifting Sling<br>Hatch Lifting Sling<br>Seat Lifting Sling<br>Seat Tools<br>Center-of-Gravity Fixture<br>Dummy Checkout Equipment<br>Anthropomorphic dummies (5 and 95 percentile)<br>Gas Supply for Pressurization of Crew Compt.<br>Pressure Controls<br>Environmental Equipment to establish/maintain various environments within the fixture such as: Sand & Dust, Salt Spray, Humidity, Heat/Cold, etc.<br>Sled Telemetry Checkout Equipment<br>Dummy Telemetry Checkout Equipment<br>Data Acquisition/Recording Equipment |
| Software | None |
| | |

TABLE 10.4-3. FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr. | Govt |
|---|---|---|---|---|
| Baseline System | | | | |
| • Static functional tests in vertical attitude using the Vertical Tower at NWC, or at the Static Test Range at Hurricane Mesa | | X | | X |
| • Environmental tests at Grumman, Calverton | | X | X | |
| Horizontal Capability Option | | | | |
| • Functional dynamic tests at horizontal speeds related to escape requirements at the High Speed Sled Test Tracks at NWC, or Holloman AFB | | X | | X |

# 10.5 MODAL VIBRATION SURVEY OF FLIGHT VEHICLES

## 10.5.1 INTRODUCTION

Modal vibration testing of a flight vehicle is considered by Grumman to be a constraint on first flight. Experience has shown that significant differences can exist between analytical and model studies, and the modal data measured on the flight vehicle. The reasons for this are many, i.e. load paths in the actual flight vehicle are different from those assumed in the analyses; "slop" or free play in joints may significantly modify the local effective stiffness; and most important, changes are introduced into the flight vehicle which have not been factored into the most recent analysis of model tests.

The specific objectives of the modal survey program are the following:

- Confirm results of analytical studies and provide data to modify the analytical programs to reflect actual vehicle dynamics
- Confirm results of the scale model program (refer to paragraph 2.11.1.2.4) and other dynamic model tests; provide data to modify models to reflect actual vehicle dynamics
- Confirm that no significant coupling exists between the control system and structure
- Identify any control system instability

The modal vibration survey will be conducted in three phases:

- I - First Horizontal Flight Orbiter in flight configuration
- II - First Vertical Flight Orbiter in flight configuration
- III - First Vertical Flight Orbiter in launch configuration

## 10.5.2 PHASE I - HORIZONTAL FREE-FREE SUPPORT

A ground vibration survey similar to that performed on airplanes will be conducted on the first horizontal flight oribter. Since this vehicle will not have flight thermal

protection skins, the scope of the survey will be limited to obtaining sufficient modal data to verify dynamic design margins and flight safety. The orbiter will be suspended in a horizontal position from soft springs (air-bag type suspension) at the interstage connections in order to simulate a "free-free" condition. Excitation will be applied to the vehicle using multiple low force electrodynamic shakers. The survey will be performed with empty fuel tanks in simulation of the atmosphere phase of the mission. This survey is a constraint on the first horizontal flight of the orbiter.

### 10.5.3 PHASE II - HORIZONTAL FREE AND FIXED SUPPORT

This survey will be performed on the first vertical flight orbiter. It will be performed in a manner similar to that described for Phase I. However, since this is a flight configured vehicle with all thermal protection systems, the scope of the test will include the measuring of all significant orbiter modes in the reentry and atmospheric vehicle configuration. An additional restraint test will provide all modal and restraint stiffness data for analytically coupling the orbiter and booster. The test will be performed with the vehicle in a horizontal attitude supported at the interstage connection (hard mounted) with known stiffness. The free-free test is a constraint on the horizontal flight of the first manned orbiter flight vehicle while the restrained test is a constraint against FMOF.

### 10.5.4 PHASE III - VERTICAL MATED

This survey will be a test of the first vertical flight mated orbiter and booster mounted vertically at the launch pad with full tanks. The major objectives are to verify the resonant frequencies and mode shapes previously determined both analytically and from scale model tests. Detailed knowledge of these factors is required to avoid control system problems due to vehicle flexibility, to avoid POGO induced vibration, and to be confident in the analytically predicted dynamic loads. Unlike the extensive series of mode surveys performed on a Saturn V Dynamic Test Article at MSFC to obtain these data, these tests will be limited to measuring a few major coupled modes in order to minimize the problems of maintaining the vehicles in a fully fueled condition for extended periods. The abbreviated program is considered feasible because it will be preceeded by extensive analyses verified by element tests of critical items such as fluid/tank interactions, and by a very detailed, extensive scale model test program which will also verify the analysis

representing the coupling between vehicles. The results of Phase I and II mode surveys will also add to the confidence in the analytical model. The abbreviated test is considered desirable because of the relatively low costs incurred compared to a more extensive program. This test program is a constraint on the First Manned Orbital Flight.

### 10.5.5 TEST SITE

The site of the Phase I and II horizontal modal surveys is at a suitable location at KSC after the orbiter has been completely assembled. The abbreviated mated modal survey in the launch configuration with full tanks is performed on the launch pad just prior to First Manned Orbital Flight (FMOF).

### 10.5.6 ANALYTICAL TECHNIQUES

The modal vibration surveys are essentially tests and as such do not require extensive analytic techniques. However, Grumman has automated the data reduction task for vibration surveys and has coupled this capability with a light pen-scope-computer interaction program to permit rapid evaluation of mode shape, phase shift, orthogonality, and conservation of momentum (for free-free modes only). Curve fitting, correction of bad data points, rotated views, and final hard copy plots of the pertinent modes are all available as options of the existing program. This program was used for the first time on the F-14A airplane vibration survey and resulted in considerable savings in man hours and elapsed time with an improvement in reliability and accuracy of the final plotted data.

In addition to this technique for automation of the data reduction task, a program for the coupling of the results of the separate tests of the booster and orbiter as well as a program to extrapolate from the tested configuration to the flight configuration are required.

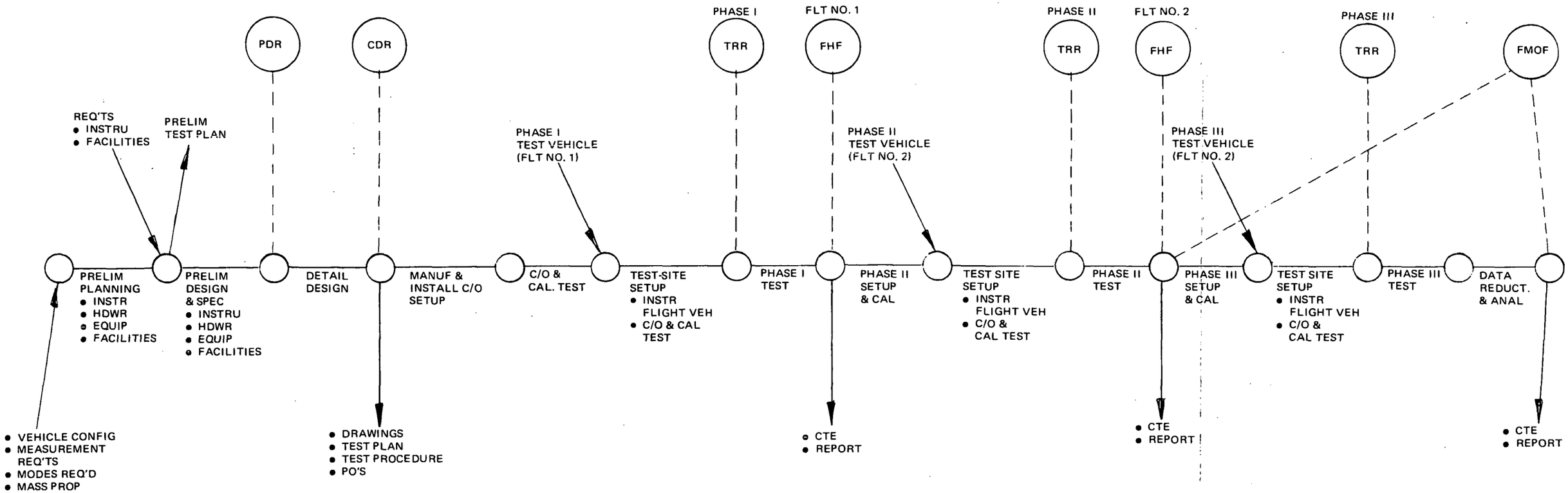




Fig. 10.5-1 Modal Vibration Survey Test Logic



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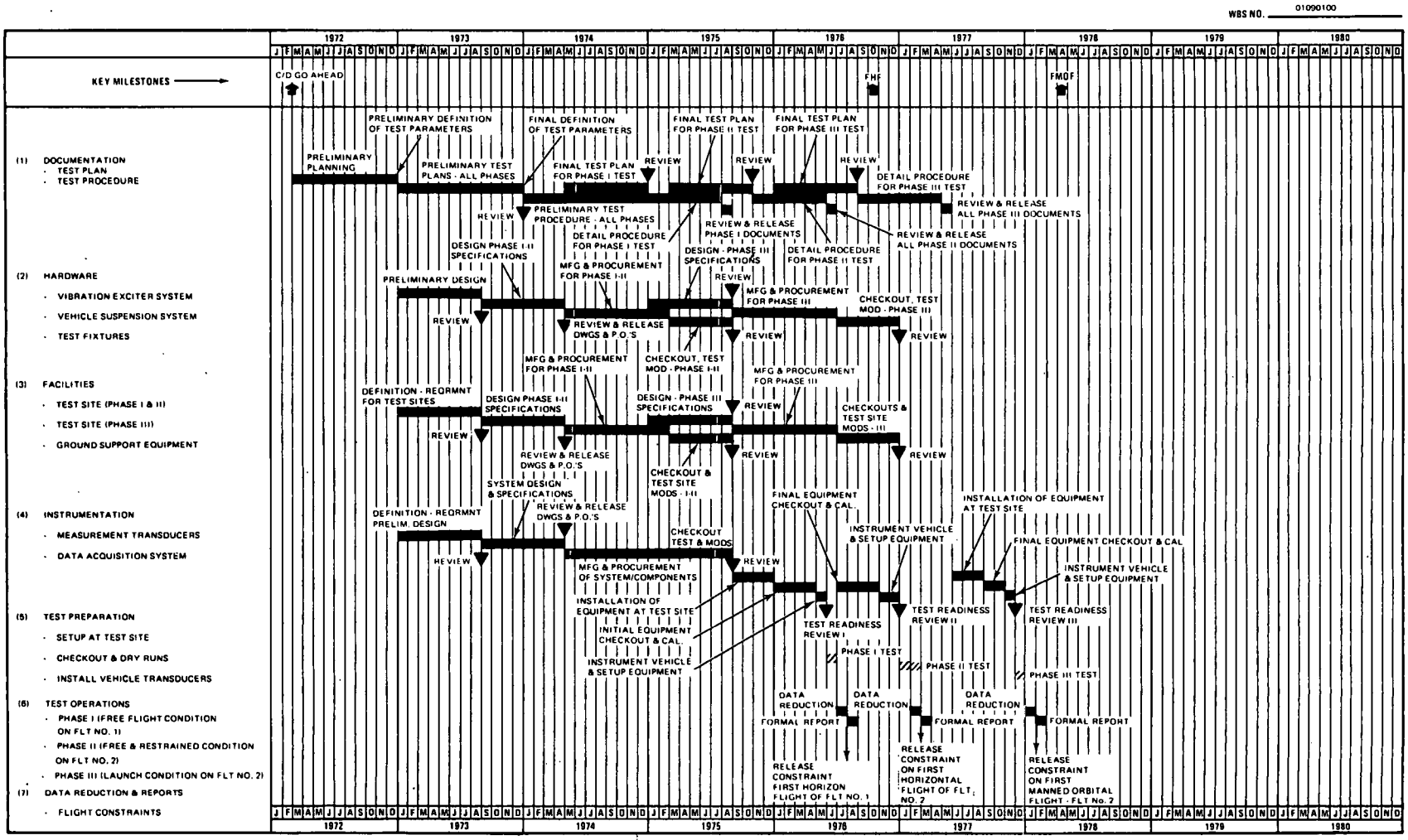



Fig. 10.5-2 Modal Vibration Survey Schedule

TABLE 10.5-1. BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

| Item | Common | Potential Common | Common | Remarks |
|---|---|---|---|---|
| Analytic Technqiues<br>• Coupling analysis to predict mated vehicle characteristics | | X | | For the launch configuration the need exists to develop accurate and efficient capability to couple the results of separate booster and orbiter vibration test results into a set of modes and frequencies of the combined booster/ orbiter vehicle. Grumman is investigating an impedance matching procedure as a possible way to proceed on this problem. Assuming success this procedure would have application to both the booster and orbiter analyses. |
| Integrated Vibration Survey<br>• Vibration mode survey of the mated vehicles in the launch condition | X | | | This survey data will be utilized to verify the analytical coupling techniques described above and results of the scale model program. The data obtained is equally applicable to the booster. |

TABLE 10.5-2. SUBSYSTEM SUPPORT EQUIPMENT/ SOFTWARE REQUIREMENTS

| Item | Requirements |
|---|---|
| Support Equipment | Vibration Exciter System (24) 150 lb Force, 4 in. D.A.<br>Exciter Control System<br>Vehicle Suspension System<br>Exciter Support Stands<br>Vacuum Pumps<br>Dynamic Measurement Transducers and Cabling (300 measurements)<br>Mass Simulations for Major Pieces of Equipment<br>Data Acquisition System<br>Data Processing System<br>Vehicle Handling Equipment (transporters, slings, dollies, etc.)<br>Vehicle Fluid Handling Equipment<br>Vehicle System Equipment required to activate and monitor vehicle hydraulic, pneumatic and electrical system. |
| Software | Program to process dynamic measurement data for model and flutter analysis. |
| | |

TABLE 10.5-3. FACILITY REQUIREMENTS LIST

| Title and Description | New | Exist. | Contr. | Govt |
|---|---|---|---|---|
| • Test Site (free-free condition) - Enclosed area with clear floor space of 250 x 200 ft and a minimum overhead clearance of 80 ft. Site must have entry access for the vehicle and be located within transportable distance of flight test area | X | | | X |
| • Test Floor - The floor in the test area must be locally reinforced to offer a measurable stiffness connection for attachment of the orbiter at its booster interface points | X | | | X |
| • Test Site (launch condition) - Launch pad or equivalent area where the mated booster/orbiter can be erected vertically in the launch configuration and be maintained in the fully fueled condition | | X | | X |
| • Hoisting System (free-free condition) - A fixed or traveling hoisting system with a load capacity exceeding the maximum dry weight of the orbiter must be provided at the test site | X | | | X |

# 10.6 INTEGRATED SYSTEMS TESTS AND SIMULATION

## 10.6.1 INTRODUCTION

The systems integration test and simulation plan delineated in this section is directed toward the support of the design and the verification of the orbiter systems and subsystems. This plan is designed to:

- Enable the establishment of the subsystem and system requirements by providing design data for conceptual and trade off studies
- Provide the tools for studies to evaluate and determine pilot, vehicle and system capabilities in performing orbiter maneuvers and tasks
- Identify design verification and engineering test laboratories, capable of independent or combined operation, for verification of the subsystem and system software/hardware performance criteria

## 10.6.2 DESCRIPTION

Three autonomous laboratories with the capability for integrated operation are employed to accomplish the systems design/verification objectives.

- Full Mission Simulation Laboratory (FMSL)
- Integrated Avionics Test Laboratory (IATL)
- Flight Controls/Hydraulic Test Laboratory (FCHTL)

These laboratories are configured as follows:

- Full Mission Simulation Laboratory (Fig. 10-6-1)
  - Avionics - math modeled
  - Non-avionics - math modeled

- Flight controls - math modeled
- Controls and displays - simulated hardware

- Integrated Avionics Test Laboratory (Fig. 10.6-2)
  - Avionics - flight type hardware
  - Non-avionics - math model/flight type hardware
  - Flight controls - math modeled
  - Controls and displays - flight type hardware
- Flight Controls/Hydraulic Test Laboratory (Fig. 10.6-3)
  - Avionics - math modeled
  - Non-avionics - math modeled
  - Flight controls - flight type hardware

The design of these laboratories is such that they can be combined into a full mission integrated test facility (FMITF) for overall hardware/software verification and end-to-end combined system testing as required. The laboratories are reconfigured during combined system testing (Fig. 10.6-4 and 10.6-5) as follows:

- Full Mission Simulation Lab:
  - Partial avionics (sensors) - math modeled
  - Non-avionics - math modeled
  - Environment - math modeled
- Integrated Avionics Test Lab:
  - Avionics - flight type hardware
  - Controls and displays - flight type hardware
- Flight Controls/Hydraulic Test Laboratory:
  - Flight controls/hydraulics - flight type hardware

10.6.2.1 Full Mission Simulation Laboratory

The FMSL (Fig. 10.6-1) is a six degree-of-freedom, all math model fixed base facility. This facility has the capability to perform functional or iterative mathematical model studies of all mission phases. It is supported by high quality, virtual image external visual displays, dedicated digital/hybrid computing equipment and special purpose Cathode Ray Tube (CRT) display graphics computing equipment. This laboratory has the capability of complete autonomous operation or when integrated with the Integrated Avionics Test Laboratory (IATL) and/or Flight Controls/Hydraulic Test Laboratory (FCHTL) performs combined orbiter system verification tests.

10.6.2.2 Integrated Avionics Test Laboratory

The IATL (Fig. 10.6-2) is a combination of ground test benches and cabin module which provide for independent engineering test of flight type hardware/software and independent design verification testing. The design of the IATL is such that the full complement of avionics equipment can be in the same relative locations as on the orbiter. The true length, number and location of lines, cables, connectors and test tie points are an accurate representation of the avionics system. Also special care is taken to accurately duplicate all subsystem input/output interface circuitry and control logic, which includes all electrical/mechanical loads. Tests start with breadboard subsystems in order to obtain early visibility of design requirements, verification and functional performance. The IATL is supported by a three axis Flight Attitude Table (FAT) for the GN&C flight motion sensors and a general purpose digital computer for initial independent engineering design requirements and verification studies. The special test equipment and test benches associated with this facility enables simulation of all avionics and non-avionics subsystems for independent open loop testing or small scale closed loop testing. For final closed loop dynamic design verification and mission verification testing, the IATL is operationally integrated with the Full Mission Simulation Laboratory (FMSL) and/or the Flight Controls/ Hydraulic Test Laboratory (FCHTL).

10.6.2.3 Flight Controls/Hydraulic Test Laboratory

The FCHTL (Fig. 10-6-3) is a dimensionally true structural mockup of the flight control surfaces and actuator structural mounting points. The hydraulic distribution system is

a true geometric duplication of the flight controls, engine gimballing and utility systems from the Auxiliary Power Unit (APU) pumps to the actuators. The complete complement of flight control surfaces and actuators are installed on this rig. The facility is supported by a general purpose analog computer, a digital function generator, a functional cockpit, a static load rig, dynamic loads and special test equipment. This facility performs both functional and evaluation tests of the flight controls/hydraulic systems during engineering development testing. For final closed loop dynamic design verification and mission verification testing the FCHTL is operationally integrated with the Full Mission Simulation Laboratory (FMSL) and/or the Integrated Avionics Test Laboratory (IATL).

### 10.6.3 LABORATORY WORK BREAKDOWN

The work breakdown with respect to vehicle milestones for the laboratories is as follows. The simulation data required to support Preliminary Design Review (PDR) are obtained from the part task simulators described in subsection 2.14. The test data required to support Critical Design Review (CDR) first horizontal flight (FHF) and first manned orbital flight (FMOF) comes from the test activities in the following facilities. The simulation program logic networks and the overall schedule is presented in Figs. 10.6-6,10.6-7, and 10.6-8 respectively.

The FMSL is used to perform real time man-in-the-loop simulation evaluations necessary in the design, analysis and verification of the orbiter performance criteria. It is also used to assess/develop the orbiter:

- Design constraints and requirements
- Control system laws and equations
- Controls and displays formating and tradeoff studies
- Flying/handling qualities evaluations

The Integrated Avionics Test Laboratory (IATL) is used:

- For the integration of avionic subsystems
- To establish requirement and formulation of flight control and data management software

- To develop/verify software production programs
- To verify the GN&C system
- To integrate and verify the avionics to vehicle non-avionics subsystem interfaces
- Installation test of flight type avionics and non-avionics subsystems (as required)

The Flight Controls/Hydraulic Test Laboratory (FCHTL):

- Demonstrates actual flight hardware operation
- Investigates stability margins of flight controls system
- Investigates malfunction logic and reconfiguration control
- Demonstrates system/subsystem interactions
- Establishes system confidence and demonstrates safety of operation

In addition the laboratories supply the data required to check the Interface Control Documents (ICD) and support the preparation of the Operational Checkout Procedures (OCP). Overall end-to-end testing is performed by combining part or all of the laboratories into a FMITF to provide:

- Orbiter mission verification testing
- Overall orbiter system hardware/software verification
- Instant analysis during flight test in the event of any contingencies

The primary advantages of this test plan for the FMITF are:

- Only one set of flight type hardware is required, therefore facility costs are minimized
- The primary work functions of design development, design verification, of both the integrated avionics and the flight controls systems are parallel tasks that cannot be performed on a single facility without high risk scheduling. But since this facility consists of three autonomous laboratories these work functions are scheduled as parallel tasks and the high risk is removed from the scheduling

- The three autonomous but integrable laboratories offer many configuration alternatives that a single facility does not, e.g., the facility reliability of avionics and hydraulic systems operating in a test environment is not as critical when one can switch the offending laboratory out of the combined test system and replace it with its equivalent mathematical model. In most cases this would permit at least some of the test objectives to be achieved until the problem was rectified

- A commercial computer with the same internal architecture and instructional repertoire as the flight article is used in conjunction with the general purpose computer in the Full Mission Simulation Laboratory (FMSL) or Integrated Avionics Test Laboratory (IATL). This would permit early flight software development in a simulation environment and thus reduce the risks on this long lead item (e.g., the IBM 4 Pi computer is equivalent to the IBM 360's). This emulator technique is the subject of further studies

- There are no duplications of facilities except in the software world. A common software executive routine with subroutine models is designed for the general purpose computers. This permits sharing of the environmental and non-avionics software and thus reduces non-flight software development costs

- The inclusion of display graphics computing equipment in the FMSL permits an early analysis of the controls and displays system. This facilitates defining constraints and requirements for display formating, software development and the ability of the crew to interpret displays and efficiently command and interrogate the data management system (DMS).

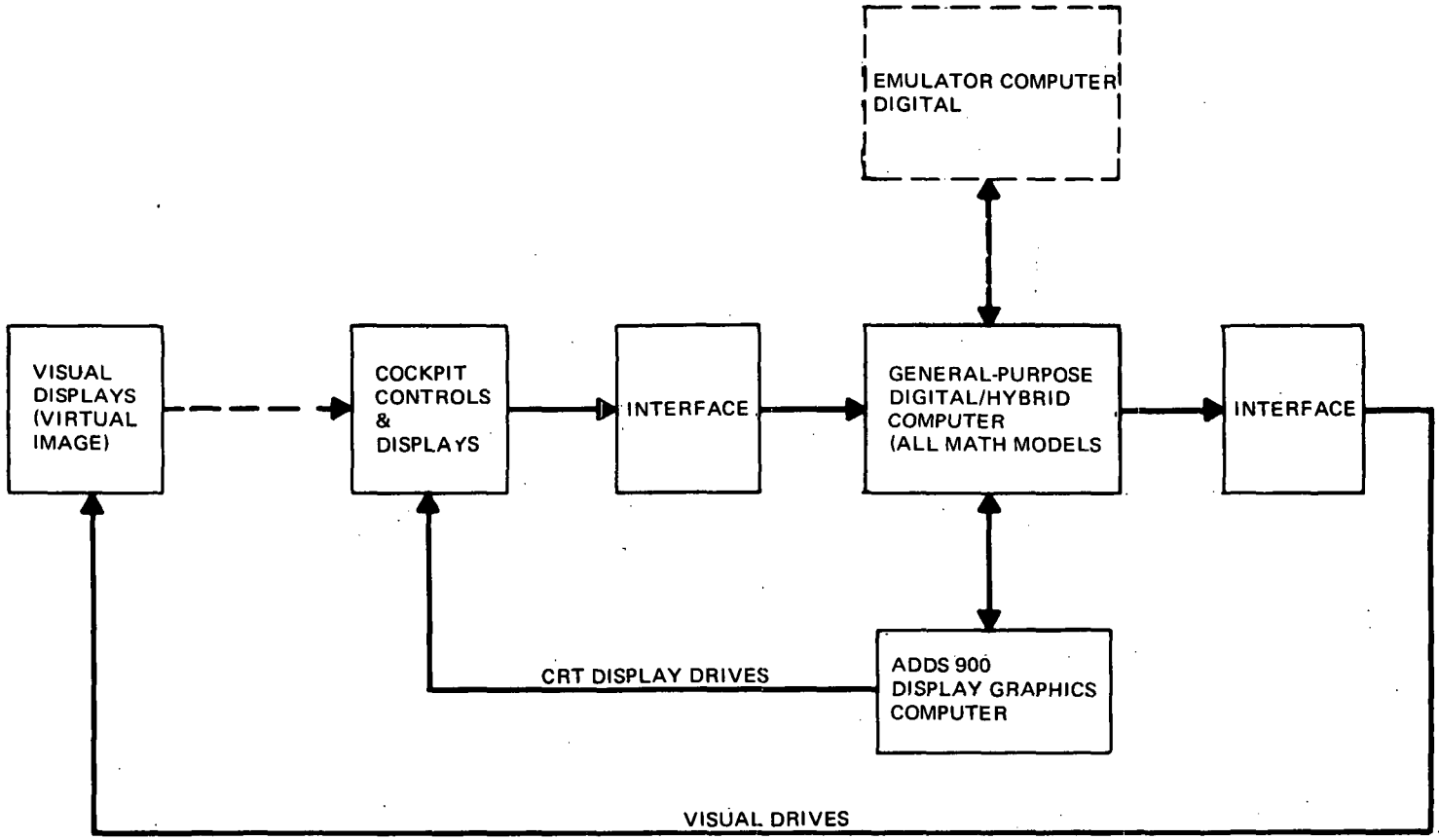



Fig. 10.6-1 Full Mission Simulation Laboratory

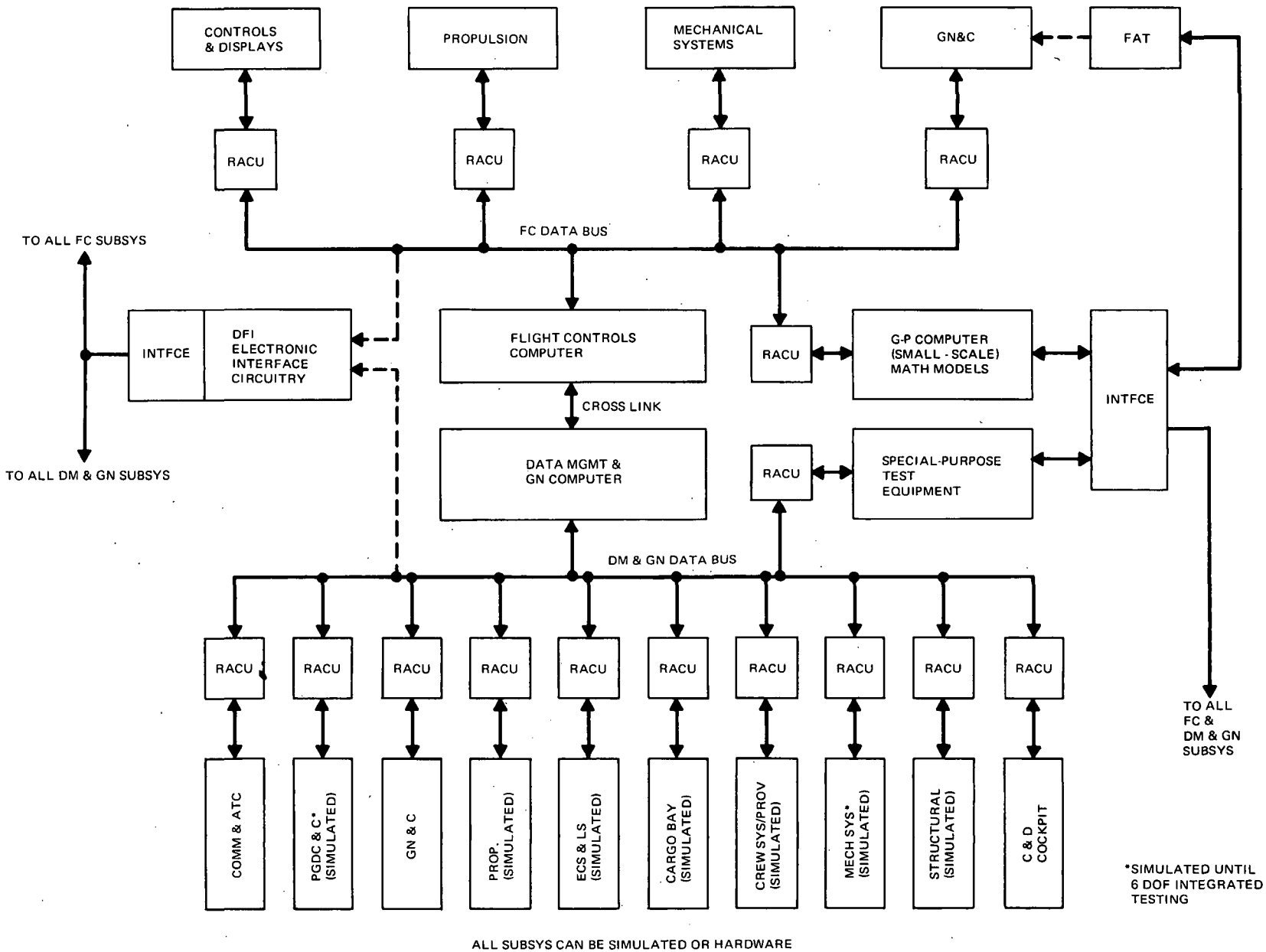



Fig. 10.6-2 Integrated Avionics Test Lab.

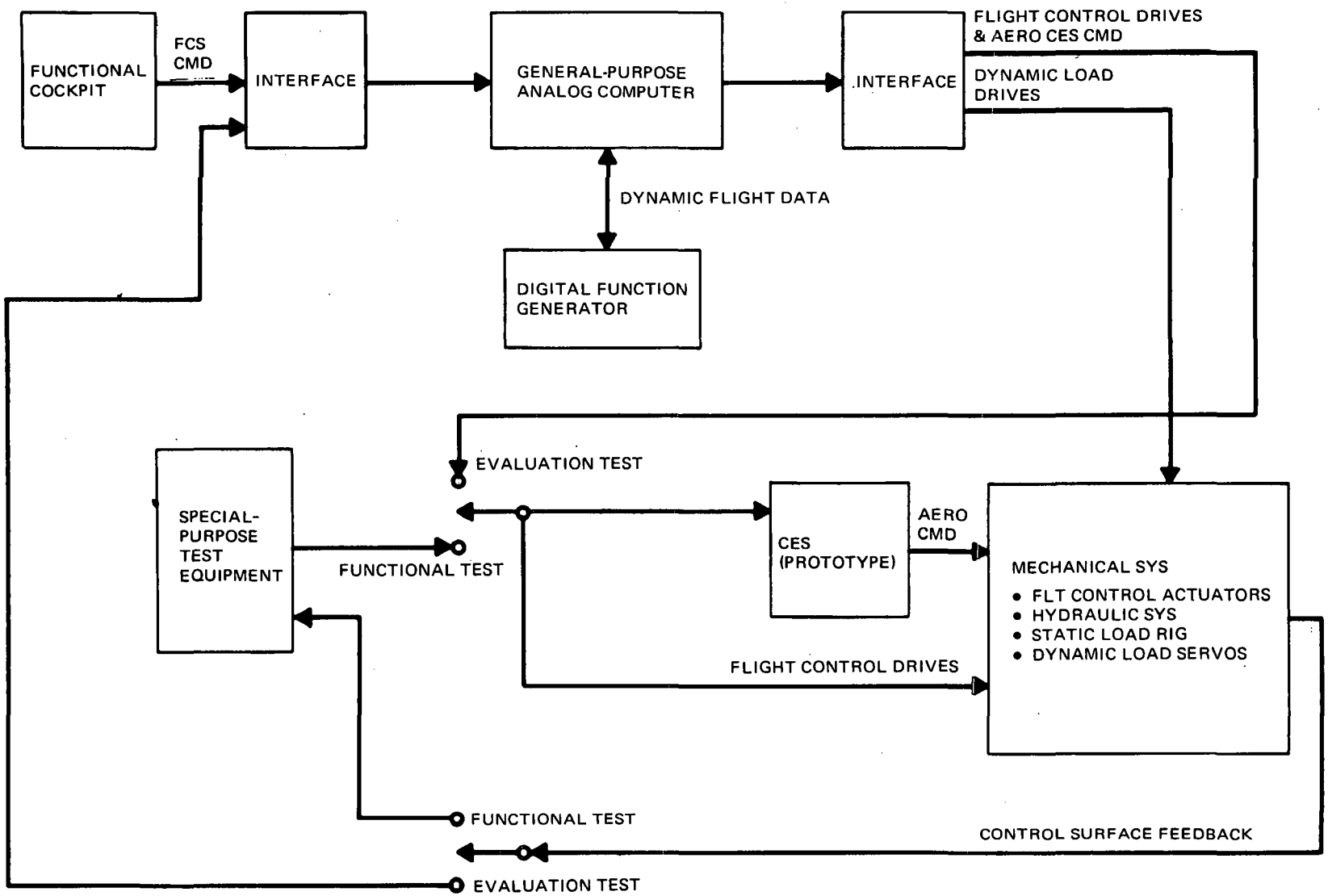
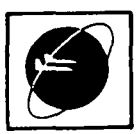



Fig. 10.6-3 Flight Controls Hydraulic Test Laboratory







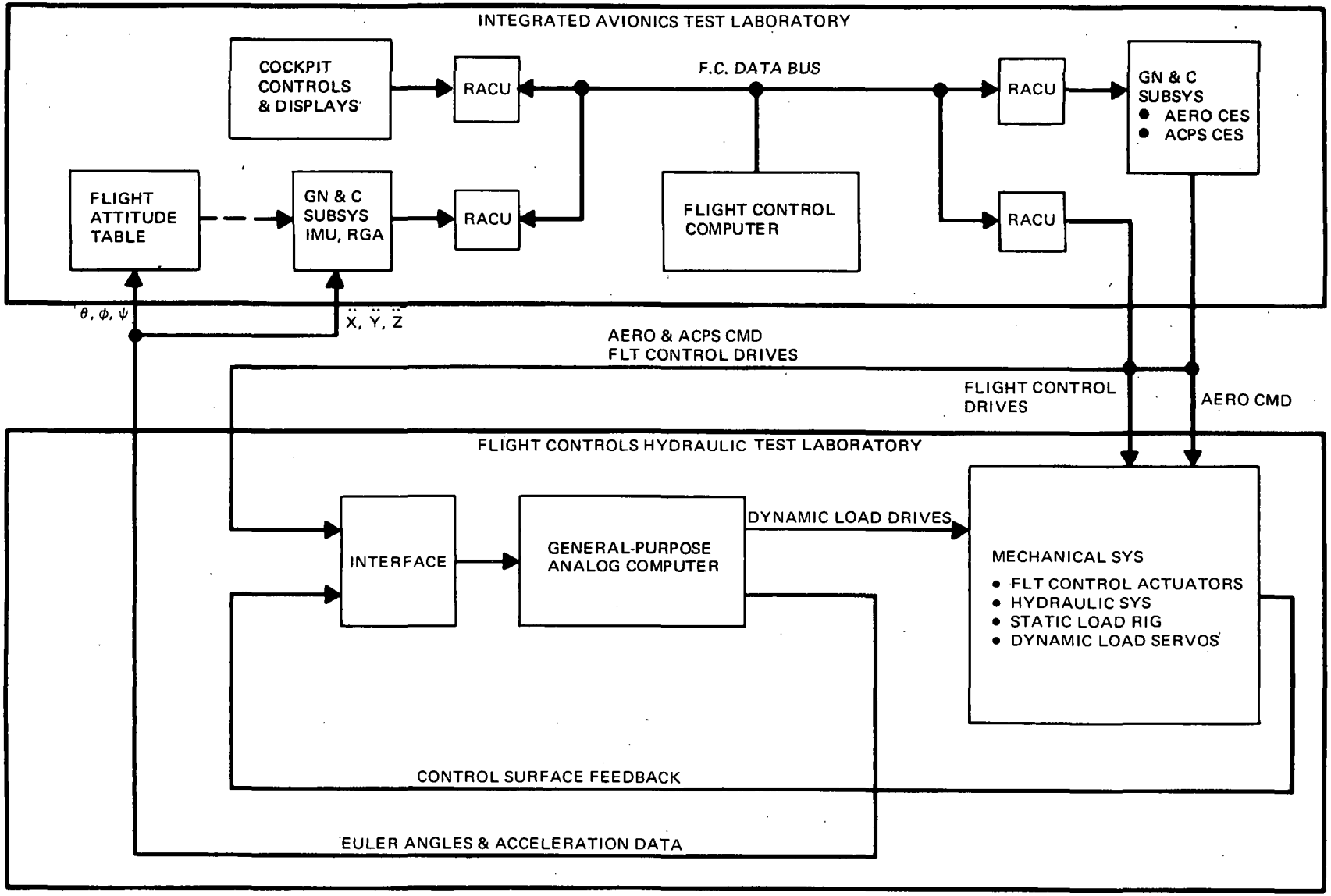



Fig. 10.6-4 Simplified 6 DOF IATL & FCHTL, Full Mission Integrated Test Facility

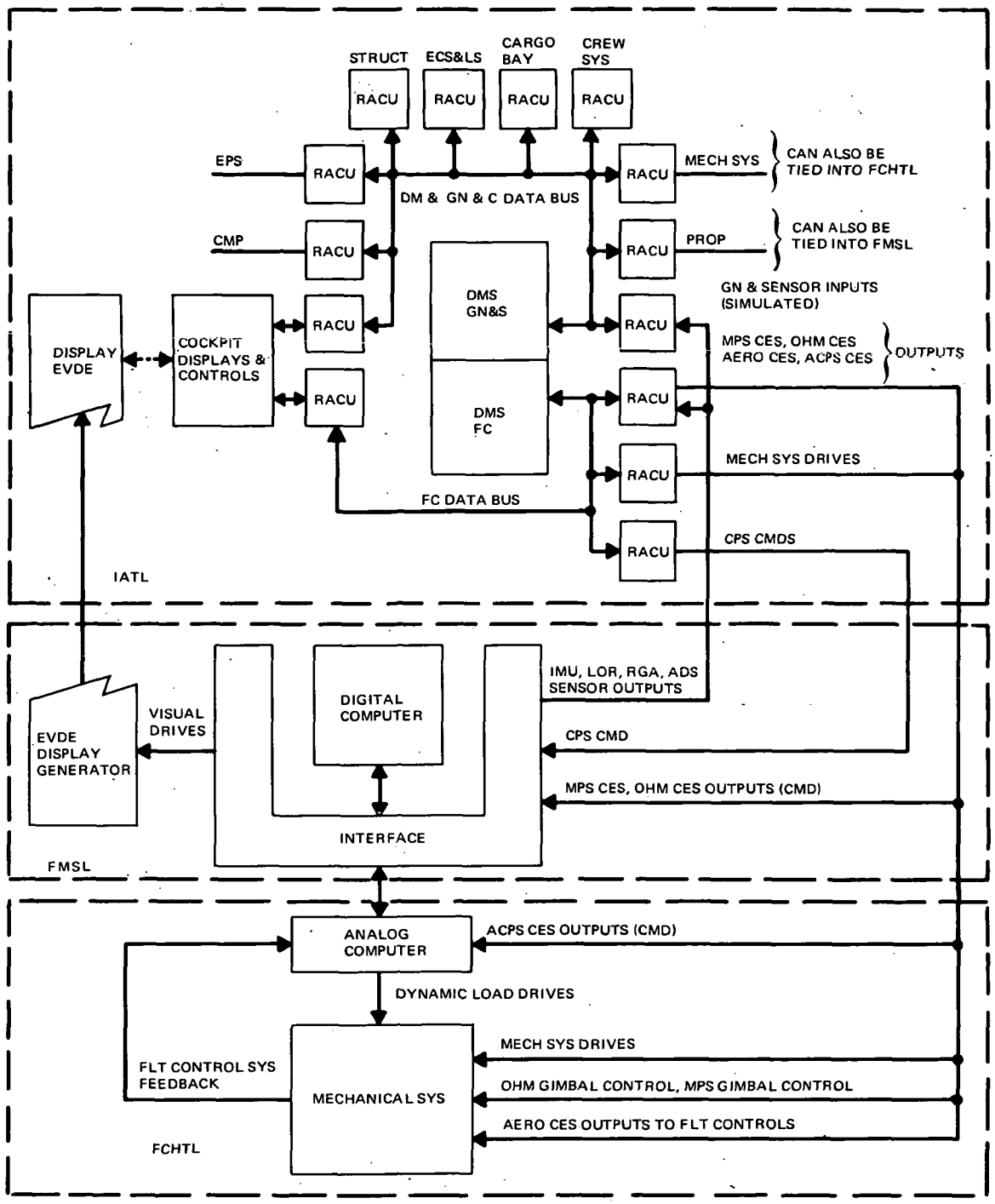



Fig. 10.6-5 Full Mission Interated Test Facility For End-To-End Simulation

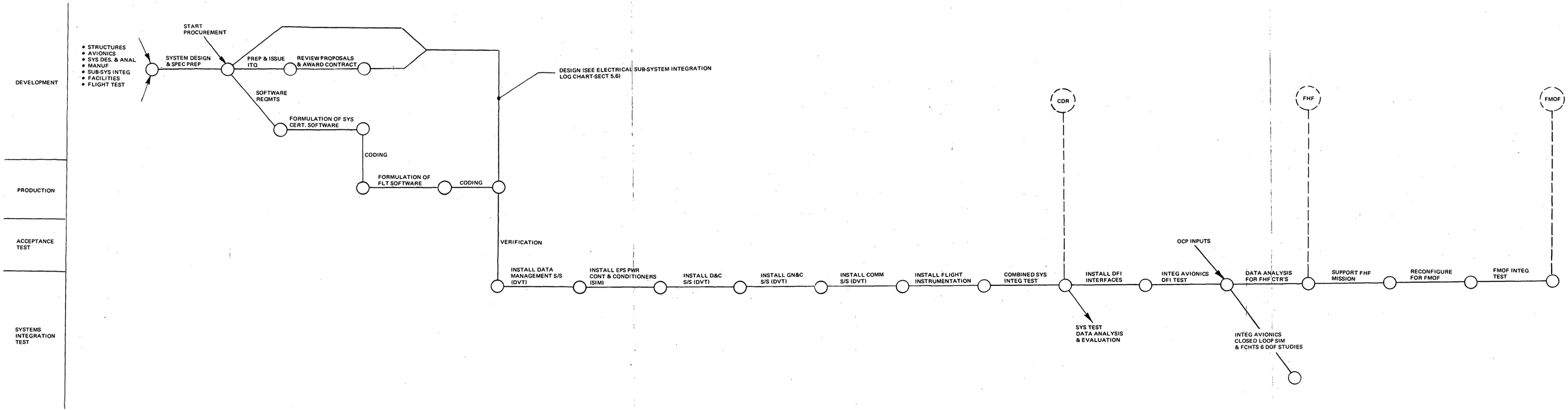





Fig. 10.6-6 Avionics Systems Integration Logic



GRUMMAN BOEING

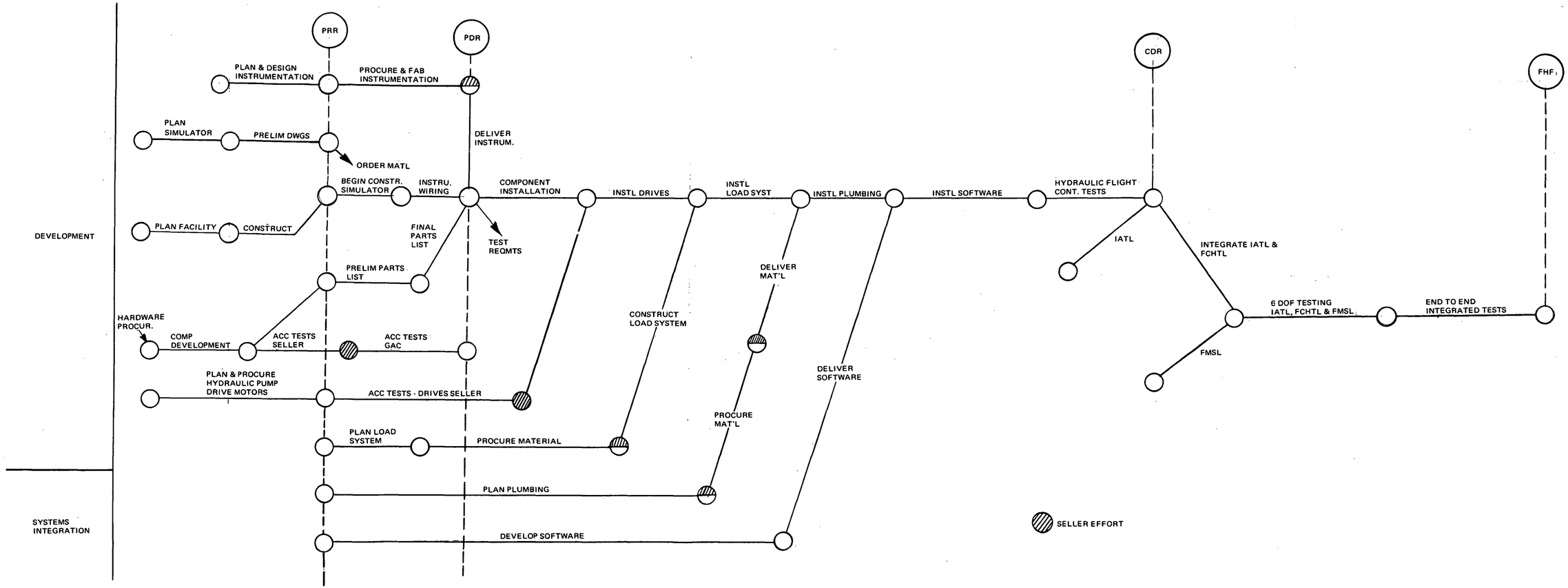



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Fig. 10.6-7 Flight Control/Hydralic Test Stand



GRUMMAN BOEING

WBS NO. 01090100 SYSTEM TESTING

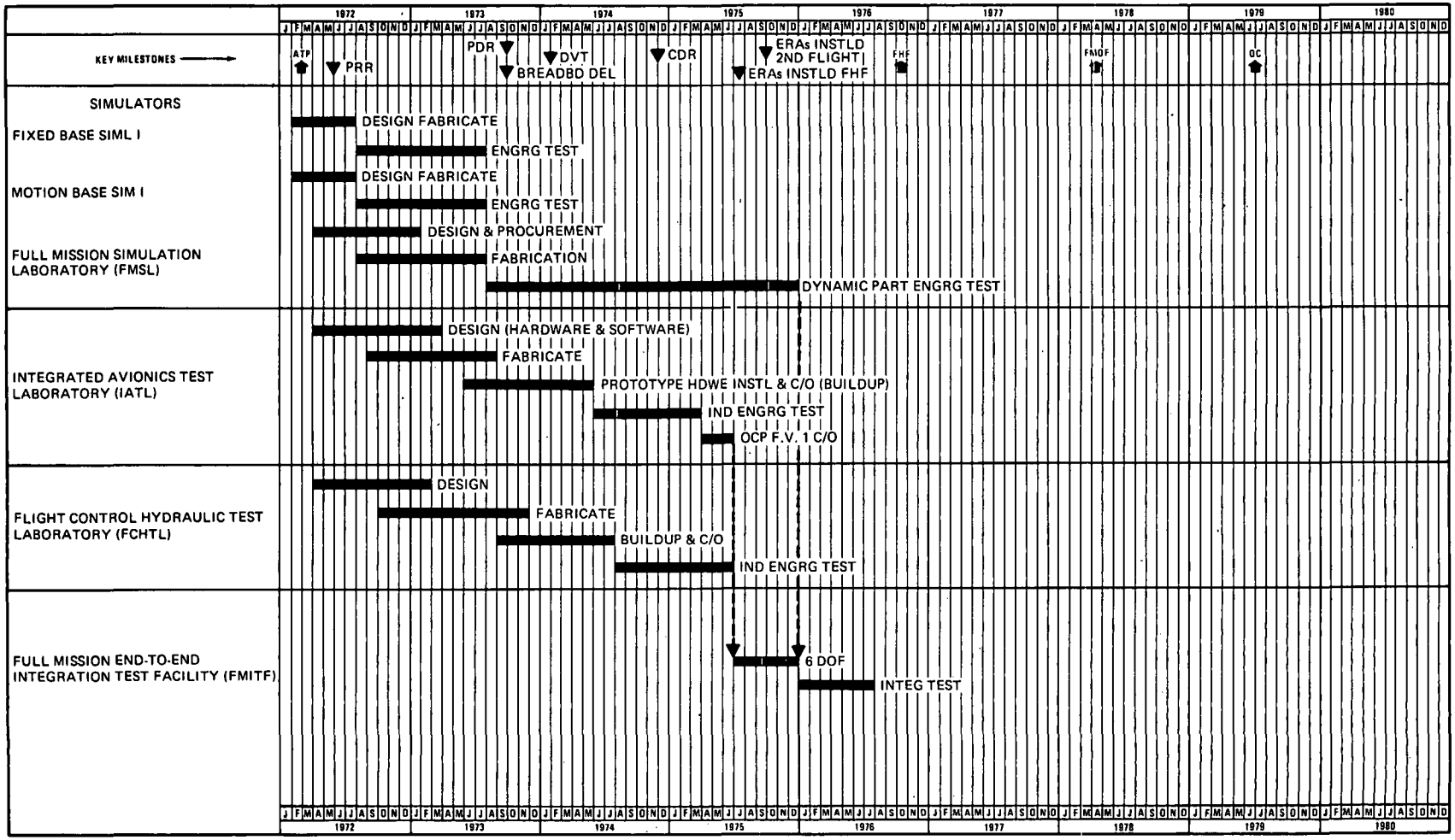


Fig. 10.6-8 Integrated System Test and Simulation Schedule

TABLE 10.6-1 SUPPORT REQUIREMENTS, NON-FLIGHT ITEMS

| Area | Requirements | IATL | FMSL | FCHTL |
|---|---|---|---|---|
| Test Equipment | | | | |
| | General purpose computers for flight environment (dynamic simulation) | 1 (Small scale Digital) | 1 Digital/ Hybrid | 1 Analog |
| | Interface equipment (A/D, D/A and special purpose) | 1/2 | 1 | 1/2 |
| | External visual display equipment for (1) Rndz & Dock (2) Cargo Manipulation (3) Approach and Landing | 0 | 1 | 0 |
| | Digital function generator (For dynamic flight data simulations) | 0 | 0 | 1 |
| | Display graphics computer | 0 | 1 | 0 |
| | Flight attitude table (for IMU, RGA) | 1 | 0 | 0 |
| | Prime movers for auxiliary pwr units | 0 | 0 | 1 |
| | Special purpose stimuli test equipment | 1 | 0 | 1 |
| | Flight deck air conditioning | 1 | 1 | 0 |
| | Avionics cooling | 1 | 0 | 0 |
| | Mobile environmental equipment (temperature only) | 1/2 | 0 | 1/2 |
| | Dummy loads (electrical, static, and dynamic forces) | 1 | 0 | 1 |
| | Functional flight decks (non-flight type) | 0 | 1 | 1 |
| Software | DM program for initial equipment checkout | 1 | | |
| | 6 DOF program for simulation testing (digital) | | 1* | |
| | Subsystem models for non-avionics checkout | 1 | | |
| | 6 DOF model for FC dynamic testing (analog) | | | 1* |
| | FTV acceptance test program for on board DM computer | 1 | | |

* The FMITF simulation test program will be the hybrid combination of these two programs

TABLE 10.6-2 FACILITY REQUIREMENTS LIST

| Title and Description | IATL | FMSL | FCHTL | New | Exist. | Contr | Govt |
|---|---|---|---|---|---|---|---|
| • Air Conditioning | 200K - BTU/HR | 200K BTU/HR | 400K - BTU/HR | X | | | |
| • 115V 60~ Single Phase | 100A | 100A | 200A | X | | | |
| • 115/200 400~ 3 Phase | 20A | 20A | 20A | X | | | |
| • 440V 60~ 3 Phase | 50A | 50A | 100A | X | | | |
| • 28.5 VDC Regulated | 100A | 100A | 100A | X | | | |
| • 120 VDC Regulated | 50A | 50A | 50A | X | | | |
| • 115/200 60~ 3 Phase | 100A | 100A | 200A | X | | | |
| • Floorspace | 2000 $ft^2$ | 2000 $ft^2$ | 10,000 $ft^2$ | X | | | |



GRUMMAN BOEING

TABLE 10.6-3 COMPUTER SUPPORT REQUIREMENT (Sheet 1 of 2)

| Keypunch* (Total Hours Per Year | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 500 | 500 | 500 | 250 | 250 | 250 | 250 | 250 | 250 | | | | | | | | 3000 |
| Machine Time | | | | | | | | | | | | | | | | | |
| 360-75 | | | | | | | | | | | | | | | | | |
| 360-67 | | | | | | | | | | | | | | | | | |
| 360-30 | | | | | | | | | | | | | | | | | |
| *7094-II | 1000 | 500 | | | | | | | | | | | | | | | 1500 |
| *1800 | 1000 | 500 | | | | | | | | | | | | | | | 1500 |
| **Sanders | | 1000 | 2000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | | | | | | | | 21000 |
| ADDS 900 | | | | | | | | | | | | | | | | | |
| **Sigma 5 | | 1000 | 2000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | | | | | | | | 21000 |
| LDRS | 250 | 250 | | | | | | | | | | | | | | | 500 |
| | | | | | | | | | | | | | | | | | 45500 |
| Programming (M/M) | | | | | | | | | | | | | | | | | |
| 7094-II | 32 | 16 | | | | | | | | | | | | | | | 48 |
| 1800 | 4 | 1 | | | | | | | | | | | | | | | 5 |
| Sanders adds 900 | | 24 | 24 | 24 | 12 | 12 | 12 | 12 | 12 | | | | | | | | 132 |
| Sigma 5 | | 32 | 72 | 36 | 24 | 24 | 24 | 24 | 24 | | | | | | | | 260 |
| LDRS | 12 | 6 | | | | | | | | | | | | | | | 18 |

RATIONALE (Explain briefly the basis for your estimate, for example, the number of revised programs or new programs anticipated)

* Dedicated to support of orbiter simulations

** To be procured and dedicated to support of orbiter simulations (or equivalent eq)
Estimates based on programmer support required for F-14 & LM simulators

* Assume 50 cards per hour



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TABLE 10.6-3 COMPUTER SUPPORT REQUIREMENT
(Sheet 2 of 2)

| | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Keypunch* (Total Hours Per Year) | 10 | 20 | 50 | 50 | 50 | 30 | 30 | | | | | | | | | | |
| Machine Time (Hr) 360-75 360-67 360-30 | 5 | 10 | 25 | 25 | 25 | 15 | 15 | | | | | | | | | | |
| Programming (Man-minutes) | 12 | 24 | 24 | 24 | 24 | 12 | 12 | | | | | | | | | | |

RATIONALE (Explain briefly the basis for your estimate, for example, the number of revised programs or new programs anticipated)

- 12 new programs generated on the F-14A Program
- Estimating 8 new programs for the orbiter

* Assume 50 cards per hour

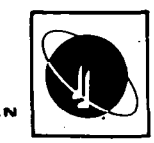
# Section 11

# SUPPORT EQUIPMENT

This section summarizes the support and special test equipment and support software that will be required during the engineering and development phase. It covers all the engineering development, mockups, and test phases of the orbiter vehicle and is presented in this section for ready reference.







SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 1 of 42)

| Subsystem | Requirements |
|---|---|
| Aerodynamic Surfaces (Assy)<br><br>Equipment | <br><br>- Support Stands (Horizontal and Vertical Erect.)<br>- Access Stands<br>- Slings, Dollies, Jacks<br>- Component Support Fixture (Install.)<br>- Component Protective Devices<br>- Tools & Fixtures for Install.<br>- Rigging Devices |
| Software | - None |
| Fuselage (Vehicle Assy)<br><br>Equipment | <br><br>- Support Stands (Horizontal and Vertical Erect.)<br>- Access Stands<br>- Slings, Dollies, Jacks<br>- Component Support Fixture (Install.)<br>- Component Protective Devices<br>- Tools & Fixtures for Install.<br>- Rigging Devices |
| Software | - None |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 2 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage Fatigue Rig Equipment | May be common for OMS $LH_2$ and $LO_2$ tanks<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- $GH_2$ Support Equipment<br>- $LH_2$ Support Equipment<br>- $LN_2$ Support Equipment<br>- Test Instrumentation<br>- Data Recording Equipment<br>- NDE Support Equipment<br>- Test Fixtures<br>- Safety Equipment |
| Software | - Data Reduction Program<br>- Thermal/Pressure Cycle Transient Program |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 3 of 42)

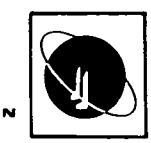
| Subsystem | Requirements |
|---|---|
| Fuselage Hydrostatic Test<br><br>Equipment | Can be common for ABPS (permanent and ferry) and OMS $LH_2$ and $LO_2$ tanks.<br>- Water Supply<br>- Water Purification Support Equipment<br>- Water Pressurization<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- Test Instrumentation<br>- Hydraulic Controls (Loading)<br>- NDE Support Equipment<br>- Test Data Recording Consoles<br>- Test Fixtures<br>- Test Article Handling/Transport Equipment |
| Software | - None |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 4 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage Acceleration Track | |
| Equipment | Can be common for ABPS and OMS tanks<br>- $GN_2$ Support Equipment<br>- $GH_e$ Support Equipment<br>- $LH_2$ Support Equipment<br>- $LN_2$ Support Equipment<br>- Water Support Equipment<br>- Test Instrumentation<br>- Test Data Recording Equipment<br>- Test Fixtures<br>- Safety Equipment<br>- Acceleration Load Controls<br>- Test Article Transport/Handling Equipment<br>- NDE Support Equipment |
| Software | - Program for acceleration load schedule, data reduction |
| Fuselage Slosh Rig | |
| Equipment | Main $LH_2$ and $LO_2$ tanks<br>- Referee Fluid Support Equipment<br>- Test Instrumentation<br>- Test Data Recording Consoles<br>- Test Fixtures<br>- Test Article Transfer/Handling Equipment |
| Software | - None |







SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 5 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage Elemental Testing<br><br>Equipment | May be common for main $LO_2$ and OMS tankage<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- $LH_2$ Support Equipment<br>- $LO_2$ Support Equipment<br>- LHe Support Equipment<br>- Test Instrumentation<br>- Data Recording Equipment<br>- Test Fixtures<br>- Safety Equipment<br>- NDE Support Equipment<br>(Small scale support rigs to be consistent with test facilities) |
| Software | - None |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 6 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage Acceptance Test Stand<br><br>Equipment | May be common for main $LH_2$ and $LO_2$ tanks<br>- $LN_2$ Support Equipment<br>- $GN_2$ Pressurization Equipment<br>- GHe Support Equipment<br>- NDE Support Equipment<br>- Safety Equipment<br>- Test Data Recording Consoles<br>- Hydraulic Load Controls<br>- Test Instrumentation (T/C, Strain Gages, Accelerometers & Transducers)<br>- Test Article Transport/Handling Equipment<br>- Test Article Transport Hardware (Protective)<br>- Test Fixtures (Separate for $LH_2$ and $LO_2$) |
| Software | - Program for: Data Reduction |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 7 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage Hydrostatic Test | |
| Equipment | Can be common for main $LH_2$ and $LO_2$ tanks used for structural qual<br>- Water Supply<br>- Water Purification Support Equipment<br>- Water Pressurization Equipment<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- Test Instrumentation (T/C, Strain Gages, Accel Trans)<br>- Load Control Equipment (Hydraulic, Servo Type)<br>- NDE Support Equipment<br>- Safety Equipment<br>- Test Fixtures, Test Stand<br>- Test Data Recording Consoles<br>- Test Article Transport/Handling Equipment |
| Software | - Data Reduction Program<br>- Mission Load Spectrum Program |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 8 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage Vacuum Chamber Test<br><br>Equipment | Can be common for OMS, $LH_2$ and $LO_2$<br>- $LO_2$ Support Equipment<br>- $LH_2$ Support Equipment<br>- $LN_2$ Support Equipment<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- NDE Support Equipment<br>- Temperature Conditioning Equipment<br>- Test Instrumentation<br>- Test Fixtures<br>- Heat Leak Measurement Devices (Vent Gas)<br>- Data Recording Consoles<br>- Test Article Transport/Handling Equipment<br>- Safety Equipment<br>- Purge System (Vehicle Simulated) |
| Software | - Data Reduction Program |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 9 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage OMS Tank Testing Chamber (DVT)<br><br>Equipment | - $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- $LN_2$ Support Equipment<br>- LHe Support Equipment<br>- Safety Equipment<br>- NDE Support Equipment<br>- Test Instrumentation<br>- Test Data Recording Equipment<br>- Temperature Conditioning Equipment<br>- Test Fixtures<br>- Purge System |
| Software | - Data Reduction Program |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 10 of 42)

| Subsystem | Requirements |
|---|---|
| Fuselage Vibration Rig<br><br>Equipment | Can be common for OMS and ABPS tanks<br>- Referee Fluid Support Equipment<br>- $LN_2$ Support Equipment<br>- $LH_2$ Support Equipment<br>- GHe Support Equipment<br>- Test Instrumentation<br>- Test Data Recording Equipment<br>- Safety Equipment<br>- Test Article Handling/Transport Equipment<br>- Test Fixtures<br>- NDE Equipment<br>- Temperature Conditioning Equipment |
| Software | - Data Reduction Program<br>- Load Spectrum Program |
| External Tank (Assembly)<br><br>Equipment | - Support Stands (Horizontal and Vertical Erect.)<br>- Access Stands<br>- Slings, Dollies, Jacks<br>- Component Support Fixture (Install.)<br>- Component Protective Devices<br>- Tools & Fixtures for Install.<br>- Rigging Devices |
| Software | - None |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 11 of 42)

| Subsystem | Requirements |
|---|---|
| External Tank Fatigue Rig<br><br>Equipment | May be common for OMS, $LH_2$ and $LO_2$ tanks<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- $GH_2$ Support Equipment<br>- $LH_2$ Support Equipment<br>- $LN_2$ Support Equipment<br>- Test Instrumentation<br>- Data Recording Equipment<br>- NDE Support Equipment<br>- Test Fixtures<br>- Safety Equipment |
| Software | - Data Reduction Program<br>- Thermal/Pressure Cycle Transient Program |
| | |

EXTERNAL TANKAGE SLOSH RIG TEST
SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 12 of 42)

| Subsystem | Requirements |
|---|---|
| External Tankage Slosh Rig Test<br><br>Equipment | Main $LH_2$ tank<br>- Referee Fluid Support Equipment<br>- Test Instrumentation<br>- Test Data Recording Consoles<br>- Test Fixtures<br>- Test Article Transfer/Handling Equipment |
| Software | - None |
| External Tankage Hydrostatic Test<br><br>Equipment | For ABPS (perm and ferry) and OMS, $LH_2$ and $LO_2$ tanks (may be common for all or some tanks)<br>- Water Supply Rig<br>- Water Purification Support Equipment<br>- Water Pressurization Equipment<br>- $GN_2$ and GHe Support Equipment<br>- Test Instrumentation<br>- Hydraulic Controls (Loading)<br>- NDE Support Equipment<br>- Test Data Recording Consoles<br>- Test Fixtures<br>- Test Article Handling/Transport Equipment |
| Software | - None |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 13 of 42)

| Subsystem | Requirements |
|---|---|
| External Tankage Acceptance Test Stand<br><br>Equipment | May be common to main $LH_2$ and $LO_2$ tanks<br>- $LN_2$ Support Equipment<br>- $GN_2$ Pressurization Equipment<br>- GHe Support Equipment<br>- NDE Support Equipment<br>- Safety Equipment<br>- Test Data Recording Consoles<br>- Hydraulic Load Controls<br>- Test Instrumentation (T/CP, Strain Gages, Accelerometers Transducers)<br>- Test Article Transport/Handling Equipment<br>- Test Article Transport Hardware (Protective)<br>- Test Fixtures (Separate for $LH_2$ & $LO_2$) |
| Software | - Program for Data Reduction |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 14 of 42)

| Subsystem | Requirements |
|---|---|
| External Tankage Structural Qual Hydro Test<br><br>Equipment | For main $LH_2$ and $LO_2$ tanks (may be common for both tanks)<br>- Water Supply Rig<br>- Water Purification Support Equipment<br>- Water Pressurization Equipment<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- Test Instrumentation (T/C, Strain Gages, Accel, Trans)<br>- Load Control Equipment (Hydraulic; Servo Type)<br>- NDE Support Equipment<br>- Safety Equipment<br>- Test Fixtures, Test Stand<br>- Test Data Recording Consoles<br>- Test Article Transport/Handling Equipment |
| Software | - Programs for Data Reduction and Mission Load Spectrum |
| | |

EXTERNAL TANKAGE VACUUM CHAMBER TEST
SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 15 of 42)

| Subsystem | Requirements |
|---|---|
| External Tankage Vacuum Chamber Test<br><br>Equipment | For OMS $LH_2$ and $LO_2$ (may be common)<br>- $LH_2$ Support Equipment<br>- $LN_2$ Support Equipment<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- NDE Support Equipment<br>- Temperature Conditioning Equipment<br>- Test Instrumentation<br>- Test Fixtures<br>- Heat Leak Measurement Devices (Vent Gas)<br>- Data Recording Consoles<br>- Test Article Transport/Handling Equipment<br>- Safety Equipment<br>- Purge System (Vehicle Simulated) |
| Software | - Program for Data Reduction |
| | |

EXTERNAL TANKAGE VIBRATION TEST
SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 16 of 42)

| Subsystem | Requirements |
|---|---|
| External Tankage Vibration Test | |
| Equipment | For $LH_2$ tank<br>- Referee Fluid Support Equipment<br>- $LN_2$ Support Equipment<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- Safety Equipment<br>- NDE Support Equipment<br>- Test Instrumentation<br>- Test Data Recording Consoles<br>- Test Fixtures<br>- Test Article Transfer/Handling Equipment<br>- Temperature Conditioning Rig |
| Software | - Programs for Data Reduction and Load Spectrum |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 17 of 42)

| Subsystem | Requirements |
|---|---|
| External Tankage Pyro-Effects Test<br><br>Equipment | $LH_2$ tank<br>- Test Fixtures<br>- Test Instrumentation<br>- Safety Equipment<br>- Test Article Handling Equipment<br>- Pyro - Actuation Device<br>- Pressurized Air Release Device |
| Software | - Data Reduction Program |
| External Tankage Fill Test of $LH_2$ Tank<br><br>Equipment | - Test Instrumentation<br>- Safety Equipment<br>- Test Fixtures<br>- Test Data Recording Consoles<br>- NDE Support Equipment<br>- $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- $LH_2$ Support Equipment<br>- $LN_2$ Support Equipment<br>- Vent Gas Measurement Device (Heat Leak) |
| Software | - Program for Data Reduction |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 18 of 42)

| Subsystem | Requirements |
|---|---|
| External Tankage $LH_2$ Subscale Section Test (DVT) | |
| Equipment | - $GN_2$ Support Equipment<br>- GHe Support Equipment<br>- LHe Support Equipment<br>- $LN_2$ Support Equipment<br>- NDE Support Equipment<br>- Test Instrumentation<br>- Test Data Recording Equipment<br>- Test Fixtures |
| Software | - None |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 19 of 42)

| Subsystem | Requirements |
|---|---|
| Thermal Protection System<br><br>Equipment | - TPS panel hypersonic test rig for vibration/ temp test<br>- Press/temp/acoustic test rig<br>- Scale to measure weight of panels<br>- Deflection probes and transducers<br>- CSC Systems for recording deflections and temperatures<br>- Diff press. transducers and readouts<br>- Hydraulic rig and control valve to simulate altitude-time profile<br>- Main heater and guard heater assembly for effective emittance measurements plus thermocouples and readouts.<br>- Ammeters and voltmeters<br>- Insulated heat sink<br>- Quartz array, pressure sealing fixture, supply tank, piping, control valves, heat and flow meter for gas infiltration and heating test<br>- Support Stands (Horizontal and Vertical)<br>- Access Stands<br>- Slings, Dollies, Jacks<br>- Component Support Fixture (Install.)<br>- Component Protective Devices<br>- Reusable Containers<br>- Tools and Fixtures for Install.<br>- Rigging Devices |
| Software | - None |

CREW STATION/EQUIPMENT & PASSENGER ACCOMODATIONS
SUBSYSTEM EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 20 of 42)

| Subsystem | Requirements |
|---|---|
| Crew Station/Equipment & Passenger Accommodations | |
| Equipment | - Boresighting equipment for camera and docking target installations<br>- Checking fixtures to check installation clearances of electrical component assemblies such as instrument panels<br>- GSE devices for ingress/egress on pad and airport |
| Software | - None |

FLIGHT CONTROLS SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 21 of 42)

| Subsystem | Requirements |
|---|---|
| Flight Controls Equipment | - Portable checkout box to mate with both ACA & TTCA connectors & be capable of functionally testing controllers without removal from booster vehicle<br>- Hydraulic actuator overhaul bench with hydraulic pressurization and metering system<br>- Actuator handling equipment required to install actuators in the orbiter<br>- Bench test equipment for hydraulic actuators |
| Software | Programs to Implement the following·<br>- Simulated aeroloads on elevons, rudder, and speed brakes resulting in loads on FC actuators for a typical mission profile<br>- Programs to determine thermal and vibrational environments that thrust vector control actuators will see during a nominal mission<br>- Programs to determine off-nominal (worst case postulating one or more failures) values for the above areas |
| | |

FLIGHT CONTROLS SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 22 of 42)

| Subsystem | Requirements |
|---|---|
| Recovery (Landing Gear & Drogue Chute<br><br>Equipment | - Nose and main gear jacks for wheel, tire and brake changing<br>- Vehicle jacks for gear cycling<br>- Nose and main gear ground safety locks<br>- Hydraulic and pneumatic strut servicing units<br>- Hydraulic power unit<br>- Electrical power unit<br>- Load application devices<br>- "Dummy Gear" for roll-around<br>- Gear assembly and disassembly tools |
| Software | - None |
| Docking & Payload Deployment<br><br>Equipment | - Hydraulic stand for silicone fluids<br>- Environmental test stand for hot and cold tests (heater blankets and $LH_2$ + circulating fans)<br>- High speed cameras, oscilloscopes and recorders for latching tests<br>- Medium pressure (1500 psi) gaseous $N_2$ storage and transfer equipment<br>- Optical facility (or laser)<br>- Instrumentation consoles |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 23 of 42)

| Subsystem | Requirements |
|---|---|
| Software | - Docking Dynamics Program<br>- Shock attenuator loads and geometry program<br>- 2-Body 6-degree-of-freedom rigid body and flexible body program<br>- NASA docking simulator |
| Pyrotechnic Devices<br><br>Equipment | <br><br>- ALINCO bridgewire resistance tester<br>- Insulation resistance (Megger)<br>- Simulator initiator<br>- Firing console |
| Software | - None |
| MPS (Subassy Flow Test<br><br>Equipment | <br><br>- Test Fixture (for mounting ducting)<br>- Engine Flow Simulator, with Remote-Op. Valving and Replaceable Flow Control Orifices (3 required)<br>- Tank Pressurization System and Control Console<br>- Low Level Sensors, Including Readout<br>- Propellant Fill and Drain System and Control Console<br>- Instrumentation and Recording System<br>- Helium Pneumatic Supply System (For Valve Actuation)<br>- Gas Leak Detection Equipment |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 24 of 42)

| Subsystem | Requirements |
|---|---|
| Software | - Component Data Reduction Program<br>- Flow Control Sequencing Program<br>- Coldflow Data Reduction Program |
| Air Breathing Engine<br><br>Equipment | - JP-4 Storage/Transfer Equipment<br>- $GN_2$ Storage/Transfer Equipment<br>- He Storage/Transfer Equipment<br>- Ground Start Cart<br>- Test Control Console<br>- Control/Simulation/Data Acquisition Computing Capability<br>- Hydraulic Servicing Unit<br>- Hydraulic Power Unit<br>- Thrust Measuring System<br>- Sound Barrier<br>- Engine Tool Kit<br>- Structure to Support Test Article |
| Software | Programs for:<br>- Test Sequence Control<br>- Data Acquisition<br>- TV Display of Test Data<br>- Data Analysis<br>- Test Reporting |
| | |

ORBIT MANEUVERING SYSTEM (OMS) SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 25 of 42)

| Subsystem | Requirements |
|---|---|
| Orbit Maneuvering System (OMS)<br><br>Equipment | Breadboard Testing<br>- Test benches for components and breadboard testing<br>- Pressure, temp, flow monitoring and control equipment<br>- $LH_2$ & $LO_2$ supply equipment (50 psi)<br>- LHe supply and conditioning equipment (up to 3500 psi)<br>- Gas Supply Rig - up to 400 psi $H_2$ & $O_2$<br>up to 500 psi He<br>OMS Integration Testing<br>- $LO_2$ & $LH_2$ Supply Equipment<br>- LHe Supply Equipment<br>- Test Control Console<br>- Altitude Firing Capability for 800 sec with steam ejector vacuum system<br>- Instrumentation, data acquisition, control equipment to support integration tests and engine hot firings |
| Software | Computer Programs for:<br>- Control Tapes for sequencing and control of the OMS integrated test rig<br>- Data Reduction |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 26 of 42)

| Subsystem | Requirements |
|---|---|
| Attitude Control Propulsion System<br><br>Equipment | - Test Control Consoles ($GO_2$, $GH_2$, $LO_2$, $LH_2$)<br>- Data Monitoring/Acquisition/Reduction Systems<br>- Test Rig Support Frames<br>- Gaseous Propellant Collection and Ducting System<br>- Hot Exhaust Gas Collection and Ducting System<br>- Sampling Equipment (Cleanliness, Moisture Content)<br>- Test Rig Flush and Purge System<br>- GHe/$GH_2$ Mass Spectrometer Leak Detector<br>- Safety Equipment |
| Software | - Computer Program to Control Engine Valve Actuation and Engine Firing Sequences<br>- Computer Program to Control Conditioning Module Operating Sequence |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 27 of 42)

| Subsystem | Requirement |
|---|---|
| Guidance, Navigation and Control<br><br>Equipment | • Operations - Flight Test Support Equipment - Horiz/Vert Flight Tests - Automated Telemetry Station<br>- Digital Computer Facilities<br>- Displays<br>- Space/Position Trackers - FPS-16<br>- Theodolite Facilities - Incl. Acquisition Radar<br>- Target Aircraft with Cooperative Transponders<br>• GN & C Integration Test Activity<br>- Flight Attitude Table<br>- Interface Equipment - Iron Monster/GN & C Equipment/FMES<br>- RF Navigation Aid Simulators<br>- Cockpit Mockup with Integrated Controls/ Displays/Controllers<br>- Miscellaneous Environmental/Cooling Equipment<br>- Test Initiation/Monitoring/Control Equipment<br>• IATS Activity - Pre Vehicle Installation Testing GN & C Equipment - BTME - For:<br>- Inertial Measurement Unit<br>- Optical System<br>- Control Electronics<br>- Navigation Aids<br>- Autoland Navigation Equip.<br>- Air Data Sensor<br>- Rate Sensors/ Accelerometers |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 28 of 42)

| Subsystem | Requirements |
|---|---|
| Software | Operations - Flight Test Support<br>- Real Time and Post Flight Data Handling<br>- Flight Test Parameter Data Extraction<br>GN & C Integration Test Activity<br>- Flight Software Package - Mission Simulation Test Software Package<br>- GN & C Equipment Integration Test Software Package |
| | |

DATA MANAGEMENT SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 29 of 42)

| Subsystem | Requirements |
|---|---|
| Data Mgmt<br><br>Equipment | - Mass memory for re-loading FC program<br>- Carry-on stimulus equipment for pre-launch checkout<br>- Special test programs for subsystem pre-launch checkout<br>- Bench maintenance complex<br>Memory Exerciser<br>General Digital Test Console<br>Tape Drive<br>Remote Terminal for Time Sharing to Central Mass Memory |
| Software | - Subsystem Diagnostics and Test Programs<br>- Mission and Equipment Simulation |
| DFI<br><br>Equipment | - Miscellaneous Electronic Lab Equipment<br>- Calibration Equipment<br>- DFI Checkout Van |
| Software | - Data reduction programs to utilize inflight calibration signals |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 30 of 42)

| Subsystem | Requirements |
|---|---|
| Telecommunication<br><br>Equipment | - Communication Subsystem Test Control Console<br>- RF Ground Station<br>- Specialized Test Equipment for Navigation and Landing Aid Equipment<br>- RF Checkout Equipment<br>- VSWR Measurement Unit<br>- Voice and Data Stimuli Equipment<br>- Environmental Test Equipment<br>- EMI Test Equipment<br>- Electrical Cable Set<br>- Automatic circuit analyzer<br>- Antenna Pattern Model Test Equipment |
| Software | Program to implement the following:<br>- Control of test sequence<br>- Data acquisition and analysis<br>- Simulation of computer control and displays & control functions<br>- Documentation of test results |
| | |

DISPLAYS AND CONTROLS SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 31 of 42)

| Subsystem | Requirements |
|---|---|
| Displays and Controls<br><br>Equipment | - D&C test bench with computer simulator<br>- Portable D&C test bench to be used in in-house test program |
| Software | - Programs to develop and modify CRT Display formats<br>- Programs to simulate DMS interface |
| Electronic Subsystem Integration<br><br>Equipment | Grumman manufactured electromechanical assemblies (distribution centers (10), cable junction boxes (24) and control panel and misc. elect. assemblies) require the following:<br>- Handling and checkout fixtures for sub and final assemblies during factory flow<br>- Shipping and handling fixtures at the line replaceable unit (LRU) level for installation/ maintenance operations<br>- Equipment for development and acceptance testing; thermal vacuum equipment, shock and vibration, thermal control rig, adapter harnesses and sundries, and checkout consoles<br>Grumman manufactured cable assemblies require the following:<br>- Handling and checkout fixtures during factory flow<br>- Interface cable harness to mate with vehicle cable system and equipment for checkout during routine maintenance and pre-flight activities including launch tower interfaces<br>- DITMCO equipment |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 32 of 42)

| Subsystem | Requirements |
|---|---|
| Software | Program for DITMCO for checkout of cable harness at bench and after installation levels |
| Electrical Power Generation<br><br>Equipment | - Fuel cell test standard programmable load bank<br>- APU test stand and dummy load facility for generators and pumps<br>- Battery test stand<br>- Supporting environmental and thermal control equipment |
| Software | - Load profile simulation for $H_2/O_2$ propellant supply and fuel cell and APU test stand programmable load banks<br>- Data reduction and analysis |
| Electrical Power Distribution<br><br>Equipment | - Integrated Avionics Test Stand (IATS)<br>- Programmable Power Supplies<br>- Programmable Load Banks<br>- Instrumentation |
| Software | - System Performance Simulation Program<br>- Data Reduction & Analysis |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 33 of 42)

| Subsystem | Requirements |
|---|---|
| Hydraulic System<br><br>Equipment | - Control/Simulation/Data acquisition computing capability<br>- Vacuum Pump<br>- Electric motor driven variable speed drives for pumps<br>- Ground Hydraulic Power Unit<br>- Programmable loads for elevons, rudder, gimbals, etc.<br>- Test gas distribution/regulation unit<br>- Structure, to simulate orbiter, for support of test article hydraulic sub system<br>- Test control console<br>- Electrical ground power and distribution<br>- Miscellaneous environmental test equipment |
| Software | Programs to implement the following:<br>- Control of test sequence<br>- Control of simulated loads<br>- Data acquisition and reduction to engineering units<br>- Simulation of DCM<br>- CRT display of test data<br>- Data analysis |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 34 of 42)

| Subsystem | Requirements |
|---|---|
| EC/LS<br><br>Equipment | Integrated Rig<br>- Data Acquisition System - 300 Channel<br>- Control and Monitoring Console<br>- Gas Analyzer<br>- Freon Servicing Rig<br>- Water Servicing Rig<br>- Oxygen Supply and Transfer Rig<br>- Nitrogen Supply and Transfer Rig<br>- $CO_2$ Supply Rig<br>- Water Supply (Demineralized, Portable)<br>- Freon Supply<br>- Metabolic Simulator<br>- Air & Liquid Flow Measurement, Noise Meter, Air Velocity Meter, Humidity Indicator<br>- Radiator Simulator and Fluid Conditioning Control<br>- Leak Detector<br>Radiator Thermal Vacuum Test<br>- Data Acquisition System<br>- Fluid Conditioning and Control Equipment<br>- Vibration Equipment<br>- Liquid Nitrogen Supply and Transfer Equipment |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 35 of 42)

| Subsystem | Requirements |
|---|---|
| Software | - Atmosphere Revitalization Section Simulation<br>- Heat Transport Section Simulation - Steady State, Transient<br>- Radiator Loop Simulation - Steady State, Transient<br>- Integrated Loop Simulation - Transient<br>- Component Performance |
| | |

CREW STATION/EQUIPMENT & PASSENGER ACCOMMODATIONS
SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 36 of 42)

| Subsystem | Requirements |
|---|---|
| Crew Station/Equipment & Passenger Accommodations | |
| Equipment | - Pressure suit donning/doffing room<br>- Portable control panel for pressure suit (2 Reqd)<br>- Power source for support of lighting mockup<br>- Simulated launch pad umbilical arm for support of ingress/egress mockup studies<br>- Simulated visual presentation for approach, landing, rendezvous and docking in support of mockup studies<br>- Photographic Equipment to document mockup studies and reviews |
| Software | - Computer program to implement simulated visual presentation |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 37 of 42)

| Subsystem | Requirements |
|---|---|
| Structural Test Article<br><br>Equipment | - Two bucket trucks with 60 ft Arms<br>- 300 Channel fatigue test controller<br>- 20 Channel power controller<br>- 500 Load actuators<br>- 500 Load links<br>- 25 TV cameras and monitors with tape system<br>- Thermal reflectance shroud<br>- Quartz lamps and reflectors<br>- 2000 channel data acquisition system<br>- X-Ray inspection equipment<br>- Eddy current inspection equipment<br>- Zyglo inspection equipment<br>- Krypton crank detector inspection equipment<br>- 1000 Linear displacement transducers, range 1/2 inch to 10 feet |
| Software | Programs for:<br>- Load Control<br>- Data Acquisition<br>- Data Reduction |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 38 of 42)

| Subsystem | Requirements |
|---|---|
| Propulsion Test Article<br><br>Equipment | - Modified Lunar Umbilical Tower Including LOX, $LH_2$, Propellent Loading Systems<br>- Nitrogen and Helium Purge Systems<br>- Elec Power, Instrumentation and Controls<br>- Support Structure for PTA on PAD<br>- Support Structure (mobile) for PTA during Horizontal Assembly Phase (Engine and Tank Replacement)<br>- Pressure Gauges, Small Vacuum Pumps, Maintenance Equipment<br>- Engine Simulator (Cold Flow Only)<br>- Flame Bucket |
| Software | - Data Reduction Program |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 39 of 42)

| Subsystem | Requirements |
|---|---|
| Escape System Test Rig<br><br>Equipment | - Sled Dolly<br>- Sled Lifting Sling<br>- Hatch Lifting Sling<br>- Seat Lifting Sling<br>- Seat Tools<br>- Center of Gavity Fixture<br>- Dummy Checkout Equipment<br>- Authropometric dummies (5 and 95 percentile)<br>- Gas Supply for Pressurization of Crew Compartment<br>- Pressure controls<br>- Environmental Equipment to establish/maintain various environments within the fixture such as: Sand & Duct, Salt Spray, Humidity, Heat/Cold, etc.<br>- Sled Telemetry Checkout Equipment<br>- Dummy Telemetry Checkout Equipment<br>- Data Acquisition/Recording Equipment |
| Software | - None |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 40 of 42)

| Subsystem | Requirements |
|---|---|
| Model Vibration Survey of Flight Vehicle<br><br>Equipment | - Vibration Exciter System<br>- Exciter Control System<br>- Vehicle Suspension System<br>- Exciter Support Stands<br>- Vacuum Pumps<br>- Dynamic measurement transducers and cabling<br>- Mass simulations for major pieces of equipment<br>- Data Acquisition System<br>- Data Processing System<br>- Vehicle handling equipment (transporters, slings, dollies, etc.)<br>- Vehicle fluid handling equipment<br>- Vehicle System Equipment required to activate and monitor vehicle hydraulic, pneumatic and electrical system |
| Software | - Program to process dynamic measurement data for model and flutter analysis |
| | |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 41 of 42)

| Subsystem | Requirements |
|---|---|
| Full Mission Integrated Test<br><br>Equipment | - General purpose computers for flight environment (Dynamic simulation)<br>- Interface equipment (A/D, D/A & special purpose)<br>- External Visual Display Equipment for (1) RNDZ & Dock (2) Cargo Manipulation (3) Approach and landing<br>- Digital Function Generator (for Dynamic Flight Data Simulations)<br>- Display Graphics Computer<br>- Flight Attitude Table (for IMU, RGA)<br>- Prime movers for Aux Pwr Units<br>- Special purpose stimuli test equipment<br>- Flight Deck Air Conditioning<br>- Avionics Cooling<br>- Mobile Environmental Equipment (Temperature only)<br>- Dummy Loads (Electrical, Static and Dynamic Forces)<br>- Functional Flight Decks (Non Flight Type) |

SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE
REQUIREMENTS (Sheet 42 of 42)

| Subsystem | Requirements |
|---|---|
| Software | - DM Program for initial equipment checkout<br>- 6 DOF program for simulation testing (digital)<br>- Subsystem Models for Non-Avionics Checkout<br>- 6 DOF Model for FC Dynamic Testing (analog)<br>- FTV acceptance test program for on board DM computer |
| | |

# GROUND SUPPORT REQUIREMENTS

COMPUTER REQUIREMENTS

Section 12

# SUMMARY OF COMPUTER SUPPORT REQUIREMENTS

The following tables summarize the software development and machine utilization requirements for the ROS Program. Machine utilization has been presented by machine type and total utilization in hours. Software development has been summarized by particular application as listed below versus each engineering subsystem.

## 12.1 SOFTWARE APPLICATIONS DEFINITIONS

The following is a definition of the types of software applications used in the tables:

- Math modeling and simulation - Strictly a software function where mathematical operations and relationships are used to represent a particular system (e.g. FMSL)
- Data banks and report generation - Data will be stored in a mass memory device for subsequent recall for analysis and report generation
- Hardware/software simulation - Techniques that require flight hardware and analog and/or digital computers in conjunction with software to conceptualize a physical event. Examples of this category are the FMITF, IATL, and FCHTL
- Operational flight software - Programming of the onboard computers for test and operational missions
- Support software - Development of ROS peculiar compilers, assemblers, utility debug routines, etc.
- Systems integration test software - Software for simulation and checkout of avionic systems. An example would be IATL
- Test data processing - Any software used for reduction of test data either in real-time or post-test
- Training devices software - Development of software for operational training devices, crew trainers, etc.

- Data acquisition - Software to be utilized in controlling the rate and format of data from various instrumentation sources. Examples are the software utilized on IBM 1800 in the Grumman low speed wind tunnel, and on the SEL 810 at the Grumman engine test stand in Calverton

The acronyms used above refer to the laboratories defined in subsection 10.6.

- FMSL refers to the "full mission simulation lab"
- IATL refer to the "integrated avionics test lab"
- FCHTL refers to the "flight controls hydraulics test lab"
- FMITF refers to the "full mission integrated test facility" which combines the FMSL, IATL, and FCHTL for overall hardware/software verification and end-to-end combined system test

## 12.2 COMPUTER EQUIPMENT

General purpose computers and special purpose hardware will be required to support each Level 5 task as appropriate.

The estimated computer machine utilization (reflected as machine time) required to support all areas is summarized below:

- IBM 360/75: 50,000 - 60,000 hours
- IBM 360/67: 20,000 - 25,000 hours
- IBM 360/30: 25,000 - 30,000 hours
- IBM 2250 or equivalent (with IBM 360/75): 1,000 - 1,500 hours
- IBM 1130: 4,000 - 4,500 hours
- Calcomp: 1,600 - 1,700 hours

- IBM 7094: 1,500 - 2,000 hours
- IBM 1800: 1,500 - 1,600 hours
- Sanders ADDS900 or equivalent: 20,000 - 25,000 hours
- Sigma 5 or equivalent: 20,000 - 25,000 hours
- LDRS: 20,000 - 30,000 hours
- IBM 360/65: 4,500 - 5,000 hours

## 12.3 WBS TABLES

The WBS tables included, relate the software categories to each Level 5 task description.

Where detailed software support materials within the individual sections of this document are thoroughly discussed, reference to that section is made within the appropriate WBS table.

## 12.4 COMPUTER SUPPORT REQUIREMENTS DATA SHEETS

The following data sheets provide program descriptions and other details associated with summary WBS Tables 12.3.

TABLE 12-1 SYSTEM ENGINEERING AND INTEGRATION
(WBS LEVEL 4, REFER TO SECTION 2)

| General Software Support Categories / WBS Level 5 | Reliability | Maintainability | Safety | Systems Integration | Certification Requirements | c/o Requirements Criteria | Crew Systems | Aerodynamics | Structural Analysis | Thermodynamics | Loads & Dynamics | Mass Properties | Trajectories | Simulation | QA Engineering | Producibility | Materials | Electromagnetic Compat. | Flight Controls Sys Int | Wind Tunnel Testing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Math Modeling Simulation | | Y | | Z | | Z | X | X | | XY | X | | Y | XY | | | | Y | | |
| Data Bank & Report Generation | X | X | Y | Y | | Z | XY | | | | | Z | | XY | Z | | | | | |
| Hardware/Software Simulators | | | | | | | | | | | | | | | | | | | | |
| Operational Flight Software | | | | | | | | | | | | | | | | | | | | |
| Support Software | | | | | | | | | | | | | | | | | | | | |
| System Integration Test Software | | | | | | | | | | | | | | | | | | | | |
| Test Data Processing | | | | | | | | | | | | | | | | | | | | |
| Training Devices Software | | | | | | | | | | | | | | | | | | | | |
| Data Acquisition | | | | | | | | | | | | | | | | | | | | Y |

(See Section 10)

LEGEND:
X - Existing
Y - Existing/requires modification
Z - New

NOTE: Multiple programs may be required for each software support category (e.g., XY, XYZ)

TABLE 12-2. AIRFRAME (WBS LEVEL 4)
(REFER TO SECTION 3)

| General Software Support Categories / WBS Level 5 | Airframe | Aerosurfaces | Fuselage | External Tanks | Thermal Protection System | Crew & Passenger Accomod | Flight Control System | Recovery | Payload Deploy/Retrieval | Pyrotechnic Devices | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Math Modeling Simulation | | X | X | | X | | Z | YZ | Z | | | | | | | | | | | |
| Data Bank & Report Generation | | | | | | | | | | | | | | | | | | | | |
| Hardware/Software Simulators | | | | | | | Z | | Z | | | | | | | | | | | |
| Operational Flight Software | | | | | | | | | | | | | | | | | | | | |
| Support Software | | | | | | | | | | | | | | | | | | | | |
| System Integration Test Software | | | | | | | Z | | Z | | | | | | | | | | | |
| Test Data Processing | | X | X | XZ | XZ | | | | | | | | | | | | | | | |
| Training Devices Software | | | | | | | | | | | | | | | | | | | | |
| Data Acquisition | | | | | | | | | | | | | | | | | | | | |
| | | (See section 3) | (See section 3) | | (See section 3) | (See subsection 10.4) | (See subsection 10.6) | X | (See subsections 3.8 & 10.6) | | | | | | | | | | | |



GRUMMAN BOEING

TABLE 12-3. PROPULSION (WBS LEVEL 4)
(REFER TO SECTION 4)

| General Software Support Categories \ WBS Level 5 | Main | Cruise (ABES) | Orbital Manuvering (OMS) | Attitude Control (ACPS) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Math Modeling Simulation | XZ | X | YZ | X<br>YZ | | | | | | | | | | | | | | | |
| Data Bank & Report Generation | | | | | | | | | | | | | | | | | | | |
| Hardware/Software Simulators | | | | | | | | | | | | | | | | | | | |
| Operational Flight Software | | | | | | | | | | | | | | | | | | | |
| Support Software | | | | | | | | | | | | | | | | | | | |
| System Integration Test Software | | | | | | | | | | | | | | | | | | | |
| Test Data Processing | Z | | Z | | | | | | | | | | | | | | | | |
| Training Devices Software | | | | | | | | | | | | | | | | | | | |
| Data Acquisition | | X | | | | | | | | | | | | | | | | | |

TABLE 12-4. AVIONICS (WBS LEVEL 4)
(REFER TO SECTION 5)

| General Software Support Categories / WBS Level 5 | GN&C | Data Management | Instrumentation | Operational | DFI | Telecommunication | Displays & Controls | Subsystem Integration (VEDE) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Math Modeling Simulation | Z | | | | | X<br>ZY | Z | | | | | | | | | | | | | |
| Data Bank & Report Generation | | | | X | X | | | X | | | | | | | | | | | | |
| Hardware/Software Simulators | Z | Z | | | | | Z | | | | | | | | | | | | | |
| Operational Flight Software | Z | Z | | | | | | | | | | | | | | | | | | |
| Support Software | | Z | | | | | | | | | | | | | | | | | | |
| System Integration Test Software | Z | Z | | | | | | | | | | | | | | | | | | |
| Test Data Processing | | | | | | Y | | | | | | | | | | | | | | |
| Training Devices Software | (See subsection 5.1) | (See subsection 5.2) | | | | | | | | | | | | | | | | | | |
| Data Acquisition | | | | | | | | | | | | | | | | | | | | |



GRUMMAN
BOEING

TABLE 12-5. POWER (WBS LEVEL 4)
(REFER TO SECTION 6)

| General Software Support Categories / WBS Level 5 | Elect Power Generation | Elect Power Dist. | Hydraulic System | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Math Modeling Simulation | Z | Z | | | | | | | | | | | | | | | | | | |
| Data Bank & Report Generation | | | | | | | | | | | | | | | | | | | | |
| Hardware/Software Simulators | | | | | | | | | | | | | | | | | | | | |
| Operational Flight Software | | | | | | | | | | | | | | | | | | | | |
| Support Software | | | | | | | | | | | | | | | | | | | | |
| System Integration Test Software | | Z | | | | | | | | | | | | | | | | | | |
| Test Data Processing | Z | Z | | | | | | | | | | | | | | | | | | |
| Training Devices Software | | | | | | | | | | | | | | | | | | | | |
| Data Acquisition | | | | | | | | | | | | | | | | | | | | |

TABLE 12-6. ECLS (WBS LEVEL 4)
(REFER TO SECTION 7)

| General Software Support Categories / WBS Level 5 | Atmospheric Revital. | Heat Transport & Heat Sink | Atmospheric Supply | & Composition Control | Water Manage. | Waste Management | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Math Modeling Simulation | XY | X<br>YZ | Z | Z | Z | Z | | | | | | | | | | | | | |
| Data Bank & Report Generation | | | | | | | | | | | | | | | | | | | |
| Hardware/Software Simulators | | | | | | | | | | | | | | | | | | | |
| Operational Flight Software | | | | | | | | | | | | | | | | | | | |
| Support Software | | | | | | | | | | | | | | | | | | | |
| System Integration Test Software | | | | | | | | | | | | | | | | | | | |
| Test Data Processing | | | | | | | | | | | | | | | | | | | |
| Training Devices Software | | | | | | | | | | | | | | | | | | | |
| Data Acquisition | | | | | | | | | | | | | | | | | | | |
| | (See Section 7) | (See Section 7) | (See Section 7) | (See Section 7) | (See Section 7) | (See Section 7) | | | | | | | | | | | | | |



GRUMMAN
BOEING

TABLE 12-7. SYSTEM GROUND TESTS (WBS LEVEL 4)
(REFER TO SECTION 10)

| General Software Support Categories / WBS Level 5 | Mockup & Simulators | Crew Station/Equipt Pass. | Payload Integration | Equipment Lines Integration | Main Propulsion/Heat Shield | Structural Test Article | Propulsion Test Article | Crew Escape System Test Rig | Modal Vibration Survey | Systems Integrated Tests | & Simulation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Math Modeling Simulation | | | | | | | Z | | | Z | | | | | | | | | |
| Data Bank & Report Generation | | | | | | | | | | | | | | | | | | | |
| Hardware/Software Simulators | | | | | | | | | | Z | | | | | | | | | |
| Operational Flight Software | | | | | | | | | | | | | | | | | | | |
| Support Software | | | | | | | | | | | | | | | | | | | |
| System Integration Test Software | | | | | | | | | | Z | | | | | | | | | |
| Test Data Processing | | | | | | YZ | Z | X | Y | Z | | | | | | | | | |
| Training Devices Software | | (See subsection 3.5) | | | | | (See Section 4) | (See Section 1.12) | | (See subsection 10.6) | | | | | | | | | |
| Data Acquisition | | | | | | Z | | | | | | | | | | | | | |

12.4.1 RELIABILITY AND MAINTAINABILITY (R&M) ORBITER DATA SYSTEM (SUBSECTION 2.1 AND 2.2)

- A fully developed and operational R&M data collection reporting system currently in use on F-14, EA-6B, E-2C and A-6E. Based on LM Systems, expanded to meet needs of measuring and tracking operational life characteristics and includes data elements of aircraft hardware systems. Additional elements are: failure time densities, mean-time-to-repair (MTTR), elapsed maintenance time, levels of maintenance, system uptime and downtime, etc.
- Disposition: Existing, No Modifications Required (Minimal)
- Computer to be Utilized: IBM 360/75

12.4.2 LEVEL OF MAINTENANCE MODEL, TURNAROUND MODEL, AND GO/NO-GO OPERATIONAL DECISION CRITERIA (SUBSECTION 2.2)

- Used to perform tradeoffs to determine effects of levels of maintenance with respect to cost, weight, space, maintainability criteria, etc., while meeting fail operational and fail safe requirements
- Assists in determining optimum maintenance policies as a function of turnaround time, maintenance and support resources, reliability/maintainability parameters and mission demand frequency
- Used to develop decision rules concerning launching with inoperative equipment and may be used to develop minimum operating equipment requirements for launch (Minimum Equipment List)
- Disposition: Existing, Modifications Required (Minimal)
- Computer to be Utilized: IBM 360/75

12.4.3 SAFETY (SUBSECTION 2.3)

- As hazards are identified they will be assigned a serial number and entered on a master listing and categorized by subsystem. Compensating provisions will be entered when available. When action is considered satisfactory, the Hazard will be closed. Periodically, total printouts or open item printouts will be required. It is expected that format will be very similar to LM failure reporting

- Disposition: Existing, Modifications Required
- Computer to be Utilized: TBD

12.4.4 DATA BANK STORAGE PROGRAM FOR ICD STATUS REPORTING (SUBSECTION 2.4.2)

- Simple status reporting listing - containing all ICD numbers, subject, responsibility, status, etc. Self-contained and all updates will be supplied when run
- Disposition: Existing, Modifications Required
- Computer to be Utilized: IBM 360/67

12.4.5 MATH MODELS: SUBSYSTEM SENSITIVITY MODELS (SUBSECTION 2.4.1)

- The program will be a simulation of the various onboard subsystems (i.e., prop., radars, ECS etc.) It will display the impact on the outputs of the subsystem, by varying the subsystem inputs. Self-contained, mathematical transformation functions will require other interfacing programs only when tied into overall simulation facility (full mission integration facility)
- Disposition: New Program
- Computer to be Utilized: IBM 360/67

12.4.6 CHECKOUT REQUIREMENTS AND CRITERIA (SUBSECTION 2.6)

- Trend data analysis math model and simulation using data banks for memory storage and statistical processing to support report generation . (See subsection 2.6.3) This program effort is to develop OBC routines in parallel with and emulating OBC capability to ensure program support. Special routines will be phase-developed to support ground checkout and flight test prior to development of operational routines
- System Integration test data and OBC test data transfer to trend data analysis for statistical evaluation and memory storage. Any subsystem test data either program interfaced to trend data analysis or entered into trend data by card or tape preparation or processing

- Disposition: New Program
- Computer to be Utilized: IBM 360/75, 1130

12.4.7 ANALYSIS PROGRAM (SUBSECTION 2.7)

- Performs generalized multivariate statistical analysis for analysis of quantitized human performance data
- Inputs - program will accept a maximum of 100 variables and 5000 observations per variable
- Outputs - consist of analysis of variance, descriptive statistics, correlative analysis, and multiple regression analysis
- Disposition: Existing, No Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.8 CREW UTILIZATION AND SCHEDULING PROGRAM (SUBSECTION 2.7)

- Permits real-time allocation of crew members and resources for shuttle operations. Major functions consist of crew activity sequences for up to 12 crew members and passengers, and for checking vehicle and mission constraints upon these activities
- Inputs: Includes number of crew personnel, crew skills, primary and secondary activity list
- Outputs:
  - Crew operational sequences and timelines
  - Cargo specialist operational sequences and timelines
  - Consummable data associated with vehicle activity
- Disposition: Existing, Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.9 SHUTTLE CREW COMPARTMENT ATMOSPHERIC GASEOUS TRACE CONTAMINANT CONTROL (SUBSECTION 2.7)

- The program estimates the concentration of crew compartment atmospheric trace contaminants and establishes a matrix which shows the various target body organs and systems effected by each contaminant. This matrix allows for an analysis of the additive effects of these contaminants upon the various body organs/systems
- Inputs
  - Inventory of shuttle non-metallic material weights and surface areas
- - Laboratory non-metallic material outgassing data for the shuttle environment
- Outputs
  - Total concentrations of atmospheric contaminants
  - The additive effects of these contaminants upon body organs/systems
  - Vehicle non-metallic material sources of these contaminants and their concentrations
- Disposition: Existing, Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.10 AERODYNAMIC PROGRAMS (SUBSECTION 2.8)

- Existing aerodynamic math modeling and simulation programs will be required to calculate aerodynamic characteristics. Section 2.8 lists and describes each computer program required
- Disposition: Existing, No Modifications Required
- Computer to be Utilized: IBM 360/75 and 360/67

12.4.11 STRUCTURAL ANALYSIS PROGRAMS (SUBSECTION 2.9)

- Math modeling simulation programs will be required to support the structural analysis effort.

- Disposition: Existing, No Modifications Required
  New Programs
- Computer to be Utilized: IBM 360/75, 360/67, 360/30, 1130

12.4.12 THERMODYNAMICS ANALYSIS PROGRAMS (SUBSECTION 2.10)

- Existing computer programs will be used to support the math modeling analysis effort. Section 2.10 lists and describes a representative set of programs that will be required
- Disposition: Existing, Modifications Required
- Computer to be Utilized: IBM 360/75, 360/67, 360/30

12.4.13 LOADS AND DYNAMICS (SUBSECTION 2.11)

- Existing Loads and Dynamics programs will be utilized and consist basically of math modeling and simulation applications. Additional program descriptions may be reviewed in subsection 2.8
- Disposition: Existing, No Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.14 MASS PROPERTY REPORT (SUBSECTION 2.12)

- A report is generated detailing mass property characteristics of each component or subsystem. Primary purpose is to track weight against vehicle configuration
- Disposition: Existing, No Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.15 GENERALIZED PF MASS TRAJECTORY PROGRAM (SUBSECTION 2.13)

- Basic analysis tool for evaluating vehicle performance, and guidance and navigation requirements. All mission phases are evaluated by modifications to subroutines
- Disposition: Existing, Modifications Required
- Computer to be Utilized: IBM 360/75 and 67

12.4.16 GENERALIZED 6DOF G&C DIGITAL SIMULATOR (SUBSECTION 2.13)

- Basic analysis tool for G&W/FCS software requirements generation, and verification. All G&N functions will be generated in subroutine form for use in this basic program. Program to be used for all flight modes
- Disposition: Existing, Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.17 QUALITY ASSURANCE-SHUTTLE (SUBSECTION 2.15)

- Q. C. material subsystem: A system integrated with materials systems to produce various action, forecast and history reports as well as inquiry response messages
- Receiving inspection subsystem: A system tied in with the materials to provide for automated action and planning reports necessary, to process and control purchased material
- Manufacturing inspection subsystem: A system integrated with Product manufacturing and configuration systems, capable of forecasting, tracking, retrieving manufacturing documentation as well as providing inquiry response messages
- CAPER-calibration and preventive maintenance equip. recall: A system which provides for automatic location and recall of all tools and test equip. requiring periodic calibration/preventive maintenance. This system also provides for technical evaluation of equipment performance
- Nonconformance reporting subsystem: A system to provide for reduction and analysis of data on nonconforming product and to status and close out corrective action when required. This system will integrate with other operational area files to produce action reports and management summaries on quality performance
- Q. C. laboratory subsystem: A system to provide technical and operational information to facilitate performance of Q. C. laboratory services
- Data reduction and analysis programs: A series of statistical programs for use by technical personnel to reduce and analyse variables data

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- Disposition
  - First Five Programs: Existing, Modifications Required
  - Last Two Programs: New Program
- Computer to be Utilized
  - First Six Programs: IBM 360/65
  - Last Program: IBM 360/67

12.4.18 ELECTROMAGNETIC COMPATABILITY (EMC) (SUBSECTION 2.18)

- Math model each transmitter, receiver, antenna, and transmission line parameters used on the orbiter. These models will be used, in conjunction with an established program, to define EMC design constraints, frequency assignments, and test frequencies
- Disposition: Existing, Modifications Required
- Computer to be Utilized: IBM 360/75 (included in original estimate)

12.4.19 WIND TUNNEL DATA ACQUISITION (SUBSECTION 2.20)

- Computer programs will be required to monitor, record, reduce, and plot wind tunnel data
- Disposition: Existing, Modifications Required
- Computer to be Utilized: TBD

12.4.20 STRUCTURAL INTEGRITY TESTING (HYDROSTATIC) (SUBSECTION 3.3.3.5)

- Data Reduction - Computer program which provides tabulated and plotted data parameters from magnetic tape data storage. Data parameters are stored via magnetic tape; tabulated listing generated via computer program, plotted data generated from magnetic tape via graphic terminal
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.21 ACCEPTANCE TEST (SUBSECTION 3.3.3.5)

- Data Reduction - Computer program which provides tabulated and plotted data parameters from magnetic tape data storage. Data parameters are stored via magnetic tape; tabulated listing generated via computer program, plotted data generated from magnetic tape via graphic terminal
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.22 VIBRATION TEST (SUBSECTION 3.3.3.5)

- Data Reduction - Computer program which provides tabulated and plotted data parameters from magnetic tape data storage. Data parameters are stored via magnetic tape; tabulated listing generated via computer program, plotted data generated from magnetic tape via graphic terminal
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.23 NOSE FAIRING ASSY QUAL TEST (SUBSECTION 3.3.3.5)

- Data Reduction - Computer program which provides tabulated and plotted data parameters from magnetic tape data storage. Data parameters are stored via magnetic tape; tabulated listing generated via computer program, plotted data generated from magnetic tape via graphic terminal
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.24 FILL TEST OF $LH_2$ TANK (SUBSECTION 3.3.3.5)

- Data Reduction - Computer program which provides tabulated and plotted data parameters from magnetic tape data storage. Data parameters are stored via magnetic tape; tabulated listing generated via computer program, plotted data generated from magnetic tape via graphic terminal

- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.25 SEPARATION TEST OF $LH_2$ TANK (SUBSECTION 3.3.3.5)

- Data Reduction - Computer program which provides tabulated and plotted data parameters from magnetic tape data storage. Data parameters are stored via magnetic tape; tabulated listing generated via computer program, plotted data generated from magnetic tape via graphic terminal
- Disposition: New Program
- Computer to be Utilized IBM 360/75

12.4.26 AERO HEATING TESTS (SUBSECTION 3.3.3.5)

- Program for data reduction and run condition storage - magnetic tape. Run conditions and data are stored via magnetic tape. Reference conditions are calculated and ratios are tabulated
- Disposition: Existing, no modifications required
- Computer to be Utilized: SEL 810A

12.4.27 THERMAL PROTECTION SYSTEM (SUBSYSTEM 3.4)

- Thermal analysis programs will be developed to verify the temperature constraints of each of the thermal materials proposed for use on the shuttle. The programs will supply time history plots. A more detailed description may be found in Section 3.4
- Disposition:
  - Existing, Modifications Required
  - New Program
- Computer to be Utilized: TBD

12.4.28 LANDING GEAR METERING PIN DESIGN (SUBSECTION 3.7)

- Analysis of landing dynamics to define metering pin contour as a function of shock strut stroke
- Landing gross weight, sink speed, cg locations, landing attitudes, tire characteristics, structural spring rates, shock strut air curves, fluid characteristics, and shock strut critical dimensions
- Disposition: Existing, Modifications Required
- Computer to be Utilized: 1130

12.4.29 LANDING GEAR FLOATATION ANALYSIS (SUBSECTION 3.7)

- Analysis to determine max wheel loads, wheel spacing, tire air pressures, etc, to be able to negotiate a limited number of passes over concrete, asphalt, etc, on a sub-soil of specific bearing strength and thickness. Airplane wt, tires, tire pressure, wheel spacing, concrete thickness, concrete modulus, soil strength
- Disposition: New Program
- Computer to be Utilized: TBD

12.4.30 RESTART CONDITIONING PROGRAM (SUBSECTION 4.1)

- Computes flow rates and temperature in feed systems based on line diameters and heat leaks
- Disposition: Existing, No Modifications Required
- Computer to Utilized: IBM 360/75

12.4.31 PROPELLANT UTILIZATION (SUBSECTION 4.1)

- Provides definition of propellant loading (based on engine M.R. control and loading accuracy) required for passively controlling flow to ensure simultaneous depletion of unlike propellant tanks
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.32 SUBSYSTEM PARAMETRIC OPTIMIZATION PROGRAM (SUBSECTION 4.1)

- Selects minimum weight feed system based on pressure and temperature, line diameter and insulation thickness
- Disposition: Existing, No Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.33 PROPELLANT MANAGEMENT PROGRAM (SUBSECTION 4.1)

- Analytical tool to define the feed system line resistances required for passively controlling flow to ensure simultaneous depletion of like propellant tanks
- Disposition: Existing, No Modifications Required
- Computer to be Utilized IBM 360/75

12.4.34 PRESSURIZATION DEVELOPMENT PROGRAM (SUBSECTION 4.1)

- Analytical tool to define the pressure temperature, flow rate of the pressurant gases and for the pressurization orifices
- Disposition: Existing, No Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.35 STRATIFICATION PROGRAM (SUBSECTION 4.1)

- Provides analytical definition of temperature/time history as a function of propellant height in tankage
- Disposition: Existing - No Modifications Required
- Computer to be Utilized: 360/75

12.4.36 PTA DATA REDUCTION PROGRAM (SUBSECTION 4.1)

- Reduction of data acquired on the PTA
- Disposition: New Program
- Computer to be Utilized: Lunar Module Data Reduction System

12.4.37 FLIGHT TEST DATA REDUCTION PROGRAM (SUBSECTION 4.1)

- Similar to PTA data reduction program except for computation of those parameters (e.g., thrust, flow rate, and delta-P which on-board system will not provide
- Disposition: New Program
- Computer to be Utilized: KSC or Lunar Module Data Reduction System

12.4.38 SLOSH AND OUTFLOW (SUBSECTION 4.1)

- Defines sloshing forces/amplitudes caused by vehicle flight maneuvers and its effect on propellant residuals. Will in addition characterize vortexing. Output of data reduction programs or engineering design data will be input to this program
- Disposition: New Program
- Computer to be Utilized: TBD

12.4.39 PROPELLANT ALLOTMENT PROGRAM (SUBSECTION 4.1)

- Means of defining propellant loading including allotments for the critical DRM, flight performance reserves, and flight losses
- Disposition: New Program
- Computer to be Utilized: TBD

12.4.40 MPS ENGINE CONTROL PROGRAM (SUBSECTION 4.1)

- Controls sequencing of MPS components, engine start/stop, TUC etc
- Disposition: New Program
- Computer to be Utilized: TBD

12.4.41 PRE-PRESSURIZATION DEVELOPMENT PROGRAM (Subsection 4.)

- Same as pressurization program except definition is for ground supplied helium during pre-launch
- Disposition: Existing, No Modifications Required
- Computer to be Utilized: IBM 360/75

12.4-42 FEED SYSTEM DYNAMIC PROGRAM (Subsection 4.1)

- Analytical definition of pressure oscillation in the feed system at transient conditions
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.43 ENGINE STEADY STATE SIMULATION (Subsection 4.1)

- NASA/engine contractor supplied - math model of the SSME steady-state operating parameters
- Disposition: New Program
- Computer to be Utilized: 360/75

12.4.44 ENGINE TRANSIENT SIMULATION (Subsection 4.1)

- NASA/engine contractor supplied - math model of all MPS parameters of interest
- Disposition: New Program
- Computer to be Utilized: 360/75

12.4.45 COMPONENT DATA REDUCTION (Subsection 4.1)

- Reduction of raw data from component test to flow meter, delta-p, line resistance, etc
- Disposition: New Program
- Computer to be Utilized: TBD - Dependent on location of component test

12.4.46 AIR BREATHING ENGINE SUBSYSTEM ANALYSIS (Subsection 4.2)

- Programs will be required to support the design, development and evaluate the performance of components and subassemblies of the air breathing engine subsystem. Section 4.2 lists and describes the programs that will be required. Requirements will be established for the data acquistion from the onboard avionics system
- Disposition: Existing - No Modifications Required
- Computer to be Utilized: IBM 360/75

12.4.47 AIR BREATHING ENGINE DATA ACQUISTION (Subsection 4.2)

- Programs will be required to perform test sequence control, data acquistion, T. V. display of test Data, Data Analysis and test reporting. Data input will be required from the on-board avionics systems
- Disposition: Existing - No modifications Required
- Computer to be Utilized: TBD

12.4.48 FEED SYSTEM PRESSURE DROPS (Subsection 4.3)

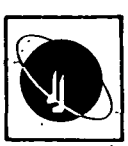
- Analytical program to determine pressure drops in feed system for different configurations, component placements, line lengths, mission phases, etc. used as a design and analysis tool and support for assembly testing and integrated testing. Also used for off design analysis. Design information, vehicle requirements, component and line characteristics, test and empirical data are input to one program
- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75 & 1130 360/67

12.4.49 FEED SYSTEM/ENGINE DYNAMIC EFFECTS (Subsection 4.3)

- Analytical program to predict dynamic effects in feed system used for design and for support of testing. Design information, vehicle characteristics, component and line design characteristics, engine characteristics are inputs to one program







- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75 1130, 360/67

12.4.50 PRESSURIZATION SYSTEM PERFORMANCE (Subsection 4.3)

- Analytical tool to design autogenous pressurization system. Includes effects on engine operation over entire operating range for cold gas autogenous top-off, design of engine heat exchangers for regenerative superheating, ullage pressurization requirements, ullage pressure behavior collapse, etc. Design information, engine performance information, analytical and empirical data on ullage pressurizing gas requirements are input to one program
- Disposition: New Program
- Computer to be Utilized: 360/75 1130, 360/67

12.4.51 OMS SYSTEM MODEL (Subsection 4.3)

- Complete math model of OMS using feed and pressurization systems programs to study and define interactions of all parts of OMS through all nominal and off-nominal mission phases. Design information, feed and pressurization systems computer programs, mission analysis will be input to one program
- Disposition: New Program
- Computer to be Utilized: 360/67, 360/75

12.4.52 INTEGRATED TEST RIG - SEQUENCING PROGRAM (Subsection 4.3)

- Engine control tapes used to input commands to engine controller on the integrated test rig
- Disposition: New Program
- Computer to be Utilized: 360/67, 360/75

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12.4.53 TURBOPUMP/GAS GENERATOR SIZING (Subsection 4.4)

- Program describes steady-state component characteristics. Output includes size, weight, flowmates, pressures, temperatures efficiencies. (Note: Description and requirements apply to the following programs: Titles: Heat Exchanger/Gas Generator Thruster)
- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75

12.4.54 GAS ACCUMULATOR SIZING AND DESIGN (Subsection 4.3)

- Quasi-steady-state program to define fluid and thermodynamic behavior of ACPS gas accumulators. ACPS mission duty cycle accumulator structural and thermal design data, and vehicle and system requirements are inputs to OMS program
- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75

12.4.55 PROPELLANT CONDITIONING MODULE STEADY STATE ANALYSIS (Subsection 4.3)

- Defines steady-state characteristics of ACPS including weights, performance, flowrates, pressures, volumes. Allows system trending analyses. Component sizing programs including: turbopump/gas generator sizing; heat exchanger/gas generator; thruster. Vehicle requirements including total impulse, accelerations
- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75

12.4.56 CONDITIONING MODULE TRANSIENT ANALYSIS (Subsection 4.3)

- Math model describing dynamic behavior of ACPS conditioning module. Defines stability boundaries of components and assembly. Used to define spec requirements, and control requirements. Information developed by the "Propellant Conditioning Module Steady-State Analysis", program. Vehicle and system requirements

- Disposition: New Program
- Computer to be Utilized: 360/75 or analog

12.4.57 CONDITIONING MODULE CONTROL TAPES SIMULATION PROGRAM (Subsection 4.3)

- These tapes command the components in the conditioning modules (turbopumps, heat exchangers) in the ACPS test. The output from "Conditioning Module Transient Analysis" program and vendor data will be used to develop the tapes. Tapes will provide sequenced start and shutdown commands to module components. Tapes will simulate the commands of the ACPS module control unit
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.58 THRUSTER FIRING TAPES SIMULATION PROGRAM (Subsection 4.3)

- This program provides commands to the ACPS thruster valves in the ACPS test programs. The tapes are prepared from G&N simulation programs (FMSL) of ACPS mission duty cycles. The tapes will command thruster valves to open and close
- Disposition: New Program
- Computer to be Utilized: IBM 360/75 (after using FMSL)

12.4.59 MEASUREMENTS/COMMAND REQUIREMENTS LIST (Subsection 5.3)

- Program provides a listing of DFI and operational instrumentation parameters
- Disposition: Existing - No Modifications Required
- Computer to be Utilized: 360/75

12.4.60 COMMUNICATIONS LINK ANALYSIS (Subsection 5.4)

- This is a math modeling and simulation program which will analyze the communication link performance margins. This involves two independent programs, one existing and one new
- Disposition: New Program
- Computer to be Utilized: IBM 360/75

12.4.61 MULTIPATH PROGRATION ANALYSIS (SUBSECTION 5.4)

- This is a math modeling and simulation program which will analysis the multi-path progration distribution for a communications link
- Disposition: Existing - Modifications Required
- Computer to be Utilized: IBM 360/75, 360/67

12.4.62 ANTENNA PATTERN ANALYSIS (SUBSECTION 5.4)

- This is a test analysis program which will analyze antenna patterns for coverage, gain and polarization
- Dispostion: Existing - Modification Required
- Computer to be Utilized: 360/75, 360/30

12.4.63 ANTENNA RADOME ANALYSIS (SUBSECTION 5.4)

- This is a test analysis program which will analyze the electrical characteristics of various RF window material types
- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75

12.4.64 CRT DISPLAY FORMAT DEVELOPMENT (SUBSECTION 5.5)

- Programs are required to develop and evaluate CRT display formats for the space shuttle. These programs will be utilized with an interactive graphics display terminal. Engineering design data established will be used to support the development of the space shuttle on-board software programs, and for the support of the FMSL and IATL facilities
- Disposition: New Program
- Computer to be Utilized: IBM 360/67

12.4.65 D&C TEST BENCH COMPUTER SIMULATOR (SUBSECTION 5.5)

- Hardware/software programs will simulate the interface between the display and control subsystem elements and the data bus or the on-board computer complex
- Disposition: New Program
- Computer to be Utilized: Mini-Computer (TBD)

12.4.66 ELECTRONIC DATA AUTOMATION (EDA) II

- Wiring information in an automated format for controlled wiring configuration and fabrication data:
  - Subsystem circuitry and hardware
  - Manufacturing methodology
  - Development flight instrumentation (DFI) interface
- Disposition: Existing - No Modifications Required
- Computer to be Utilized: 360/65 for Wiring requirements; 360/30 used as printer

12.4.67 ELECTRONIC DATA AUTOMATION (EDA)II (SUBSECTION 5.6)

- Wiring information in an automated format for controlled wiring configuration and fabrication data:
  - Subsystem circuitry and hardware
  - Manufacturing methodology
  - Development flight instrumentation (DFI) interface
- Disposition: Existing - No Modification Required
- Computer to be Utilized: IBM 360/65 for wiring requirements; 360/30 used as printer

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12.4.68 FUEL CELL/APU TEST SIMULATION PROGRAMS (SUBSECTION 6.1)

- Three programs are involved:

  1) $H_2/O_2$ propellant supply temp. and pressure simulation

  2) Fuel Cell electrical load simulation

  3) APU electrical and hydraulic load simulation

  These three programs will be used to control the propellant supply valves and regulators and the programmable electrical and hydraulic loads during the FC/APU tests.

- Disposition: New Program

- Computer to be Utilized: TBD

12.4.69 FUEL CELL/APU DATA REDUCTION/ANALYSIS (SUBSECTION 6.1)

- This program will be used to compile data derived from FC/APU tests and perform various algorithms with the data in order to efficiently analyze the test results. Data from test stand acquisition system

- Disposition: New Program

- Computer to be utilized: LDRS

12.4.70 LOAD ANALYSIS PROGRAM (SUBSECTION 6.1 and 6.2)

- This program will be used to construct load profiles during the design/development program. These profiles will be updated to reflect the various mission configuration and equipment changes that take place throughout the program. The load profiles are used as a basic for the power system design. This program is similar to the LM load analysis programs. Subsystem design data

- Disposition: New Program

- Computer to be Utilized: 360/75

12.4.71 POWER SYSTEM ANALYSIS PROGRAM (SUBSECTION 6.1 and 6.2)

- This program is a mathmatical simulation of the Power System. It is used to analyze the operation of the system with various input and configuration conditions as a part of the design development effort. This program is similar to the OAO and LM system analysis programs. Data from load analysis program
- Disposition: New Program
- Computer to be utilized: 360/75

12.4.72 ELECTRICAL POWER DISTRIBUTION SUBSYSTEM SIMULATION PROGRAMS (SUBSECTION 6.2)

- This program will be used as part of the IATL program to control the operation of the EPDS to simulate actual subsystem operation
- Disposition: New Program
- Computer to be Utilized: Computer for IATL

12.4.73 EPDS DATA REDUCTION/ANALYSIS PROGRAM (SUBSECTION 6.2)

- This program will be used to efficiently evaluate the results of the IATL testing of the EPDS. The program will compile the test results and perform various mathmatical operations on the data to aid in the efficient evaluation of the tests. Data acquired at IATL
- Disposition: New Program
- Computer to be Utilized: TBD

12.4.74 STATIC TEST ARTICLE MASTER DATA REDUCTION PROGRAM (SUBSECTION 10.2)

- Program will convert all measured data to engineering units, solve two-dimensional strain/stress data (rosettes). Correct for temperature effects, solve for thermal stresses, tabulate and plot and tabulate all data. Must accept data tape from all data acquisitions used at all test facilities

- Disposition: Existing - Modifications Required; New Program (for thermal stresses and gradients)
- Computer to be Utilized: IBM 360/75

12.4.75 STATIC TEST ARTICLE LOADS CONTROL (SUBSECTION 10.3)

- Program will accept loads spectrum and temperature information and write tapes to be used in automated control of loads and temperature applications. Should be compatible with programs used for analytical derivation of loads, temperatures and life spectrum and preferably accept outputs directly from these programs. Control tapes will be used in 300 channel fatigue test controller (refer to Table 10.2-2)
- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75

12.4.76 STATIC TEST ARTICLE DATA AQUISITION (SUBSECTION 10.2)

- Program will format and collate all transducer location, identification and calibration constants and produce control tape for 2000 channel data acquisition system. (Refer to Table 10.2-2.) Control tape to be compatible with data acquisition system
- Disposition: New Program
- Computer to be Utilized:

12.4.77 PTA SOFTWARE (SUBSECTION 10.3)

- Refer to Section 4.0 for software description
- Disposition: Existing - No Modifications Required; Existing - Modifications Required; New Program
- Computer to be Utilized: 360/75, 67, (LDRS, CDC 3200)

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12.4.78 GUS DATA REDUCTION PROGRAM (SUBSECTION 10.5)

- Batch program for determination of aircraft modes. Program logic is currently used for F-14 and will be modified to include shuttle geometries. Tape from GUS data acquisition system - output isometric plots
- Disposition: Existing - Modifications Required
- Computer to be Utilized: 360/75 with IBM 2250 peripherate

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